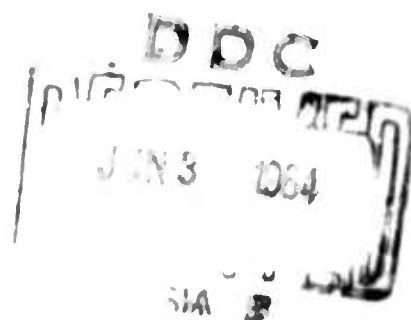
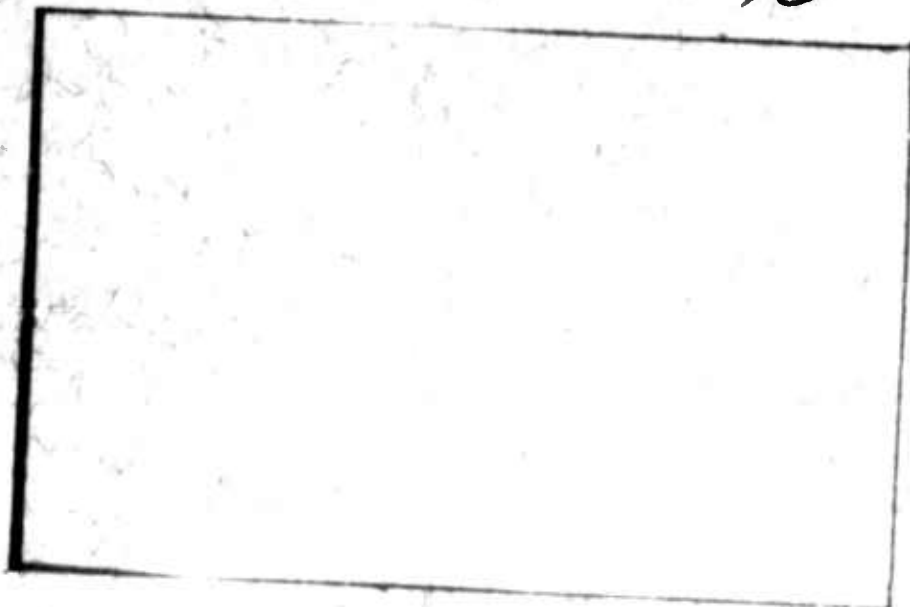


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NORMAN K. WALKER ASSOCIATES, INC.
Bethesda, Maryland

Preliminary Report

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Report No. 8

THE ACCURACY OF THE AZON
GUIDED BOMB AS AFFECTED BY
BATTLE CONDITIONS IN WORLD WAR II

BY

Alastair Anthony
Norman K. Walker
Elizabeth DeSocio

Edited:

Norman K. Walker
P. Payne

Approved:

Norman K. Walker

For

U. S. Army Human Engineering Laboratories
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ABSTRACT

The AZON bomb was studied as part of an investigation into the effects of battle stress on the accuracy of control systems in which a human operator is required to perform a task of tracking and guiding a missile to a target. The AZON system provided an example of a single axis (AZimuth ONLY) control with acceleration response of low stiffness and long time delay. These features could be easily simulated for the purpose of establishing a basis for comparison with results of experimental studies of human operators. It was conceivable that, if an appreciable loss of accuracy of AZON under battle conditions were observed, it could be attributed to deterioration in the operator's skills under these conditions, and might be compared directly with losses observed in experiments with artificially imposed stresses.

It was found that the AZON bombardiers achieved a high degree of proficiency during their training, practically implementing the full capability of the system against the long narrow targets, particularly railway bridges with straight approaches, for which the system was designed.

When these bombardiers, and others with similar training, attacked real targets in Italy, Northwest Europe and Burma, their results ranged from close to the training standard down to complete ineffectiveness. On some occasions the poor result was due, at least in part, to the unsuitability of the target but on others the cause is most reasonably attributable to a degradation of control ability, presumably due to combat stress. Good results were most frequent in Burma where enemy opposition was slight, less frequent in Europe, and did not occur in Italy where the opposition was strongest, but in all cases the average results in a war theater were inferior to the average results when the same crews were in training.

The data collected for the AZON bomb agrees with the results for similar German Systems and is only a small part of the total operational experienced available relating to operator performance under conditions of combat stress, most of which is summarized in the main report under this contract.

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INTRODUCTION

This preliminary report is the result of a suggestion by the authors to the United States Army Human Engineering Laboratories that the detailed study of the accuracy achieved with human-operator guided bomb, AZON, in World War II might reveal a reduction of skill of the trained bombardier in combat, as compared to the results achieved in training.

The AZON is particularly suited to such an investigation since the task presented to the operator is of control against a line target in one (1) plane only and this is very similar to certain laboratory tracking tasks studied in References 1, 2, and 3. and Appendix I.

It was known from a detailed study of the physiological changes due to combat that changes in tracking ability might reasonably be expected to occur. Previous work had also shown that in the laboratory, the effect of some stresses was to cause a slowing down of the operator response to a tracking error and hence a major increase in the amplitude of the oscillatory errors.

Films were known to exist of certain of the AZON bomb drops during the training and in combat, so the oscillatory component could be measured under both conditions.

If it could be established that the AZON control task was similar to the laboratory tracking tasks, and if a noticeable increase in the oscillatory error component ("cyclic" error) was seen to be present in wartime, then this could be taken as a direct measure of combat stress. Note that as the AZON bomb would not be dropped unless the target was visible, the question of degradation due to poor visibility of the target does not arise, or if it did, this would appear as an error in the direction of the average path of the bomb ("aim" error).

HISTORY OF DEVELOPMENT

The AZON bomb and its associated equipment was developed by the Gulf Research and Development Corporation under the supervision of the National Defense Research Committee⁵. The history of development is very thoroughly recorded in the progress and final reports prepared by Gulf (References 6, 7, 8, and 9). These reports also contain very satisfactory information on the technological features of the bomb, the problems encountered and the ways in which these were solved. Technically the development was well nigh perfect in the sense that the end product had all the properties inherent in the design concept. Bombs were available for training squadrons in January, 1944 and equipment and trained crews first reached an operational theater (Italy, 15th Army Air Force) in April, 1944.

THE OPERATIONAL REQUIREMENT

Initially the requirement for a dirigible high angle bomb was simply to provide some degree of correction for errors of conventional high altitude bombing. Despite the precision of the bomb sights, and under ideal proving ground conditions, the average error of 169 feet in range and 186 feet in deflection. The sources of these errors are discussed in a later chapter in connection with the RAZON bomb. The main hope of reducing these errors lay in applying some effective form of guidance to the bomb during its fall. The bomb, still primarily a ballistic missile falling under gravity, would become a guided missile to the extent that horizontal forces would be generated to drive it sideways or alter its range. Obviously since very large dynamic air pressures are available the corrective forces would be developed aerodynamically.

A fully automatic bomb (or 'homing' bomb), which would steer itself towards the target, was impractical at the time. A target-viewing bomb equipped with television relaying its position to a remotely situated operator received a lot of attention but was abandoned in favor of the simpler concept of an observed bomb steered by command of the operator. The problems of steering in range are more formidable than those of correcting in azimuth, as will be seen from the discussion of the RAZON system, and under the urgency of war time the idea of making a system quickly available steered in azimuth only was accepted as an interim part solution to the general problem. The very partial nature of this technical solution made the AZON bomb a highly specialized weapon, suitable for use only against certain types of targets. Further, it was required that AZONs should be interchangeable with regular bombs in the bomb racks of the standard heavy bombers B-17 and B-24, and that the inclusion of AZON equipment in a bombing airplane should not disqualify it in any degree from performing regular bombing.

Steering in azimuth only was simple because it did not require knowledge of when the bomb would hit the ground. All that was required was that the trajectory of the bomb should be restricted to a surface which passed through the target. To establish this reference surface the bombardier

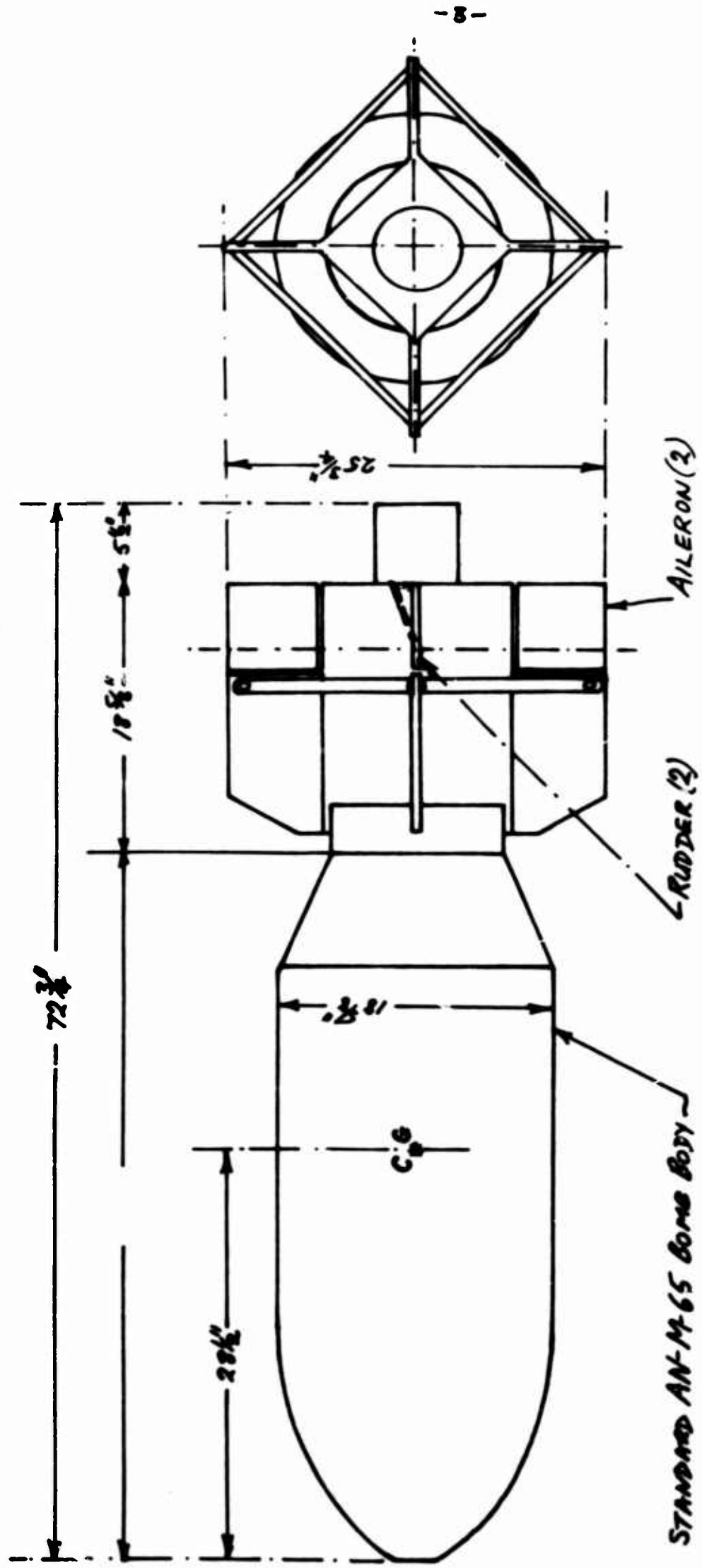


FIG 1 THE AZON BOMB (VB-1)

required a line marked on the ground so that the surface would be generated by the sight lines from his eye to the ground line. The ground line did not need to be vertically beneath the airplane or even stationary provided that its forward end was anchored on the target. Furthermore the target needed to be linear, with its axis in the reference surface. It also needed to be long because the range error was still present (was in fact increased by the azimuth control) and so the point of impact along the reference line was indeterminate over a very considerable distance. In realistic terms this means that AZON was suitable only for attacking long bridges or viaducts with fairly straight approaches, the direction of attack being near enough aligned to the railway or road so that the bombardier could use the tracks as the ground reference.

All this was quite clear in the minds of the sponsors and developers and they went ahead successfully developing AZON for precisely this specialized duty.⁵

THE AZON BOMB -- TECHNICAL DESCRIPTION

The AZON bomb (VB-1) was the standard AN-M-65 1000 lb. high explosive aircraft bomb adapted for guidance in azimuth (right or left deflection), but not in range, by the removal of the normal fixed tail unit and the substitution of a radio-controlled one. The special tail had a central compartment containing the radio receiver, gyroscopes and actuators, and externally, a pyrotechnic flare which would burn for 50 seconds with a nominal 600,000 candlepower emission.

Tail fuzeing was deleted for lack of space. All AZON bombs were nose-fuzed to burst on impact.

The tail was cruciform and had moveable flaps on each of the four fins. Two of these acted as ailerons to stabilize the bomb so that it did not roll as it fell. The other pair acted together as a rudder steering the bomb to right or to left of the plane of its trajectory. The rudder was driven by an electric motor in response to commands received. If there were no commands the rudder returned to center. Full travel was 15 degrees each way and was reached in 0.7 seconds. The bomb responded by yawing to a steady angle of about 12 degrees at which incidence a side force coefficient (c_L) of approximately 0.57 was developed. The period of oscillation in yaw was from 0.5 to 1.0 seconds, depending on speed. Thus the bomb responded to command by accelerating sideways after a time delay of 0.9 seconds or so.

The amount of side force depended on speed, which was a function of release height and distance fallen, modified by the history of control applications increasing the drag during the fall. At sea level, after falling from 15,000 feet with control applied during the last 5 seconds, the speed was estimated as 850 feet/second (Gulf, Reference 8). The corresponding dynamic pressure is 855 lb/square foot. On a reference area of 1.8 square feet (the cross section

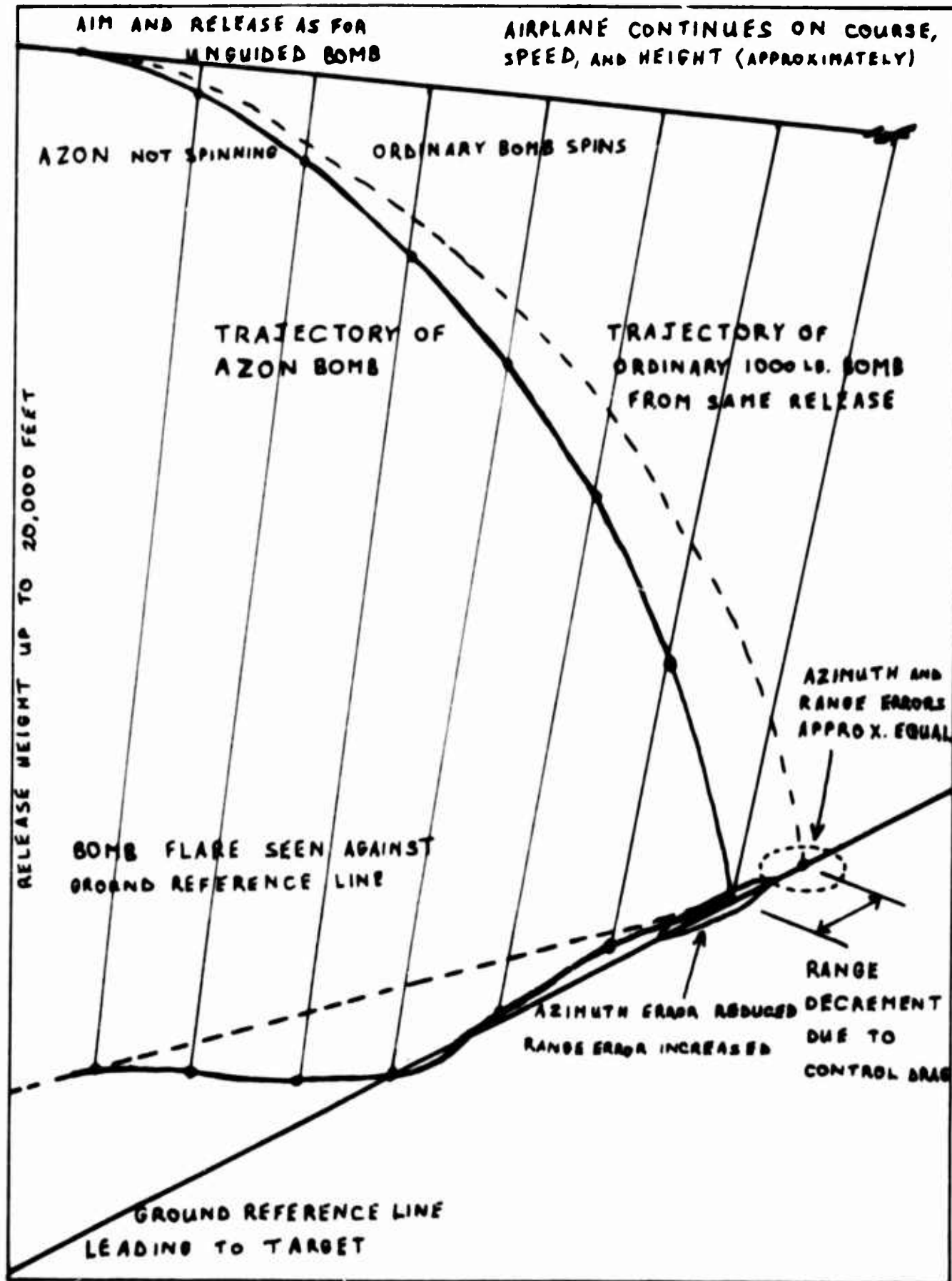


Figure 2. ELEMENTS OF AZON GUIDANCE SYSTEM

of the bomb case) the sideforce $c_L = 0.57$ gives a side force of 895 lb and a lateral acceleration of 28.3 feet/second per second. Therefore, viewed from 15,000 feet, the bomb had a sideways acceleration of 28.3/15 milliradians per second per second. That is to say, the control system STIFFNESS was 1.89 mil/sec².

Similarly, when dropped from 10,000 feet, the bomb's velocity at impact was 720 feet/second. This gives an angular stiffness of 2.03 mil/sec². When dropped from 5,000 feet the velocity at sea level was 560 feet/second giving a stiffness of 2.46 mil/sec². In a single drop from 15,000 feet the stiffness through 10,000, 5,000 feet to sea level, because of the compensating effects of increased distance, increased speed and increased density as the altitude decreased, was practically constant at 1.89 mil/sec².

Thus the system may be represented closely by an acceleration response in a single axis movement, of stiffness 1.89 mil/sec² with a time delay of 0.9 seconds.

The bombardier was provided with a simple 3-position control stick (left-center-right) for signalling his commands. He viewed the falling bomb directly without any telescope or other optical aid.

Prior to release the bomb was aimed in the ordinary way using the Norden sight. The only necessary change from ordinary bombing was the setting in of a larger trail angle to compensate for the average drag increment of the AZON due to the application of control.

It is apparent from the technical description of the AZON bomb that the system offers a perfect example of the single axis tracking task. The bombardier sees the bomb as a spot of light against the ground and applies commands right, zero or left to keep it on the line. He has nothing else to do at this time to distract him or to complicate his task. It is not necessary for the airplane to maintain straight and level flight at constant speed and height provided that these are kept within reasonable limits so as not to impair the bombardier's view. Therefore the quality of the guidance and the terminal result is due solely to the bombardier's skill. Any change in the result should be indicative of a change in skill and in the absence of any external interference this would apparently be due to changes within the man. (See detailed results in Appendix I.)

RESULTS OF CONTRACTOR'S TESTS

In the course of the development the contractor made a number of test drops against an idealized target. The falling bombs were photographed by 16 mm motion picture which also recorded control application. They made traces of the bombs as seen against the ground with the rudder positions indicated. A typical example is reproduced in Figure 3 showing the characteristic sinusoidal variation of the trace about mean line not always coincident with the ground reference line. The minimum period of the oscillation is roughly 4 seconds occupied by the four commands left, zero, right, zero, each taking 0.7 seconds to evoke a response, plus the bombardier's time to recognize the response and quench it with the opposite command.

The azimuth error evidently consists of two parts, this oscillatory deviation about the mean, which for lack of a better term we have called the "cyclic" error; and the displacement of the mean from the axis of the target, which we refer to as "aim" error. Of course it is necessary that the mean line be parallel to the long axis of the target otherwise a component of the range error is introduced. Looking at the contractor's tests the mean cyclic error is 1.65 mil, taken over 17 bomb traces. The mean of all the aim errors about the mean was 1.70 mil. The total is 2.45 mil.

The contractor's tests were all made from the standard height of 15,000 feet above the target. Thus the linear miss distance averaged 2.45 times 15 feet, which is 36.7 feet. The mean of the actual impact distances as measured for this sample of 17 bombs was 41.5 feet. 9 of the bombs hit within 25 feet. The other 8 bombs were 40 feet or more away from the aim line.

RESULTS ACHIEVED BY AZON CREWS IN TRAINING¹⁰

AZONs were used in 3 theaters during World War II:

1. Mediterranean area, 15th Air Force
2. Western Europe, 8th and 9th Air Force
3. Burma, 10th Air Force.

In preparation, Army Air Force Board Project (T-1) 13 was established to provide training. This was accomplished at Fort Dix, New Jersey, with the practical bombing exercised over the Eglin ranges based on Orlando, Florida.

The first phase provided a squadron of six B-17 airplanes and crews. This unit dropped 108 bombs during their training. An interim report on the project, dated 8 May 1944, gives the following summary:

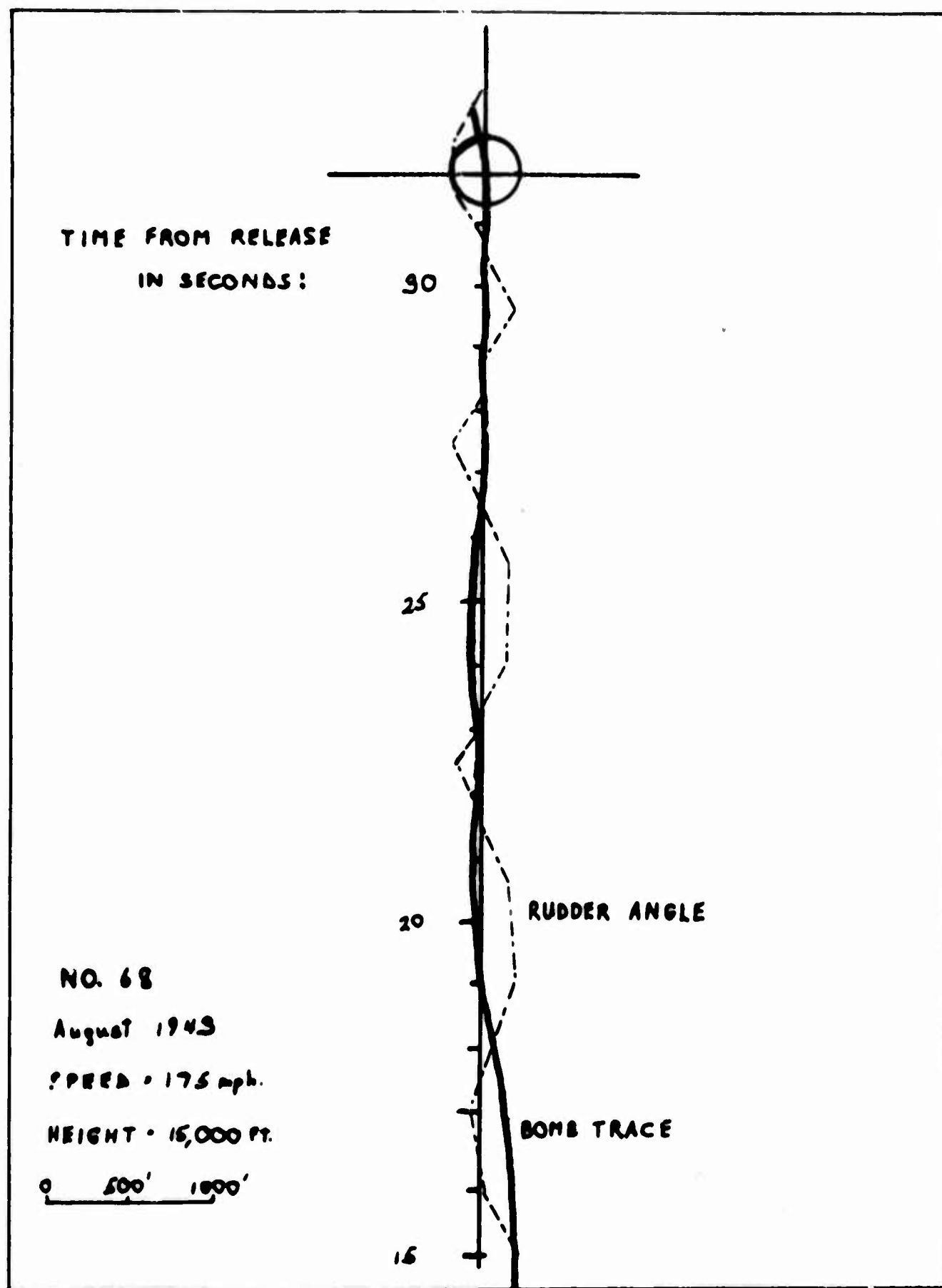


Figure 3. TYPICAL TRACE OF AZON AGAINST STRAIGHT LINE TARGET -
CONTRACTOR'S TESTS

Total number of bombs	108
Deffective	50
Satisfactory	58
Deflection 50 feet or less	51 (88%)
Average range error	88 feet short
Average circular error	261 feet
Circular error corrected for 88 feet range error	248 feet

It is not very illuminating to refer to an average circular error of 261 feet in a distribution in which 88 percent lie on a strip of 100 feet wide. Clearly the average deflection (= azimuth) error is well below 50 feet. If the distribution is assumed to be Gaussian the 50 percent half width is only 21 feet which is slightly better than the figures from the contractor's tests. At this narrowness the circular error will relate almost entirely to the range dispersal. We may note with interest that the average fall was 88 feet short, equal to 5.9 mil at 15,000 feet. In so large a sample it is likely that this is due to a persistent under-estimation of the trail angle of these bombs when receiving a fair amount of control. The range dispersal of 248 feet is notably larger than that for ordinary bombs from this height (169 feet).

The crews trained in this first phase were sent to the 15th Air Force in Italy. 2 months later they bombed the Avisio Viaduct. This action is discussed in a later section of this chapter.

We have a record of 103* bombs dropped by the 10 crews in this squadron. The miss distances in range and deflection are given in Table 1, and are plotted as frequency diagrams in Figure 4. Unfortunately the height of the airplanes are not given and cannot be assumed to have been always 15,000 feet as in the contractor's tests because mention is made of the bomb being satisfactory down to 4,000 feet. A glance at the errors in range shows that they are too small for bombing from 15,000 feet. Half the bombs fall within ± 55 feet of the target in range. AZON bombs could not possibly give range errors smaller than the average of ordinary bombs from the same height and speed and in general the errors must be appreciably larger. Error magnitudes are roughly proportional to release height. To make the ± 55 feet for the B-24 AZONs compatible with ordinary bombs and with other AZONs it is necessary for them to have been released at a much lower average height, approximately one half of the nominal 15,000 feet.

That is to say, 76 percent within ± 2.65 mil or, approximately 50 percent within ± 1.5 mil.

This compared with 50 percent within ± 21 feet (= 1.4 mil) for the B-17 squadron and ± 2.45 mil for the contractor's tests.

* Actually only 98 miss distances were recorded or otherwise noted.

It will be noted that no allowance is made for change in system stiffness due to change in height. No allowance is necessary, in fact, partly because changes in stiffness are slight and partly because the range of stiffness is all below 10 mils/sec², where, as shown in Appendix 1, stiffness ceases to have much effect on accuracy. In this stiffness range the accuracy is determined mainly by the clarity of the observer's vision. This is partly the reason why the Gulf operators could not get quite such close figures as the young servicemen. In addition (and more importantly) the contractor's tests included with deliberately large launch errors, and experimenting with different controlling techniques.

For future reference in this report 50 percent within ± 1.5 mil will be used as the standard of accuracy in training with AZON.

The B-24 squadron, having completed training, was ordered to Burma. While in transit it received orders to divert to England, to join the 8th Air Force.

Another B-24 squadron was trained at Fort Dix and Eglin during the summer of 1944 in readiness for service in Burma. We have no information on their training record beyond the fact that they dropped 200 bombs, twice the number of their predecessors, and therefore were presumably trained to at least the same standard of proficiency.

TABLE 1: AZON SQUADRON IN TRAINING

<u>BOMBARDIER</u>	<u>MISS DISTANCES IN FEET</u>									
Lacy	x	x	-75	-120	x	0	0	50	0	0
			40	-350		0	0	0	0	-60
Butler	x	0	x	x	x	x	x	0	x	0
		-125						0		0
Schelzi	x	x	x	x	0	0	0	0	0	-
					50	10	0	200	150	
Busby	x	x	x	x	-30	0	20	0	20	0
					0	-40	40	50	0	20
Sonnenfield	x	x	x	-50	0	0	-100	0	0	x
				100	75	0	0	-50	100	
Halverson	250	x	0	0	0	-20	-600	0	0	-
	-175		-200	-600	0	75	0	?	-250	
Washington	0	x	0	50	0	x	0	x	0	0
	0		0	150	200		-150		0	0
Legh-Page	0	x	0	x	0	0	0	-50	x	0
	50		150		-150	0	0	0		0
										-100
Hargis	-100	x	-50	0	0	0	-60	-600	0	0
	-50		50	-50	-1000	-100	-100	0	50	-150
Bullard	0	-70	-400	0	0	0	0	0	x	-
	0	0	0	0	0	-150	0	50		

Upper figure azimuth miss distance, positive to right. Lower figure range miss distance, positive over. x denotes defective bomb.

Total in sample - 98. 31 defects, 67 effective sample.

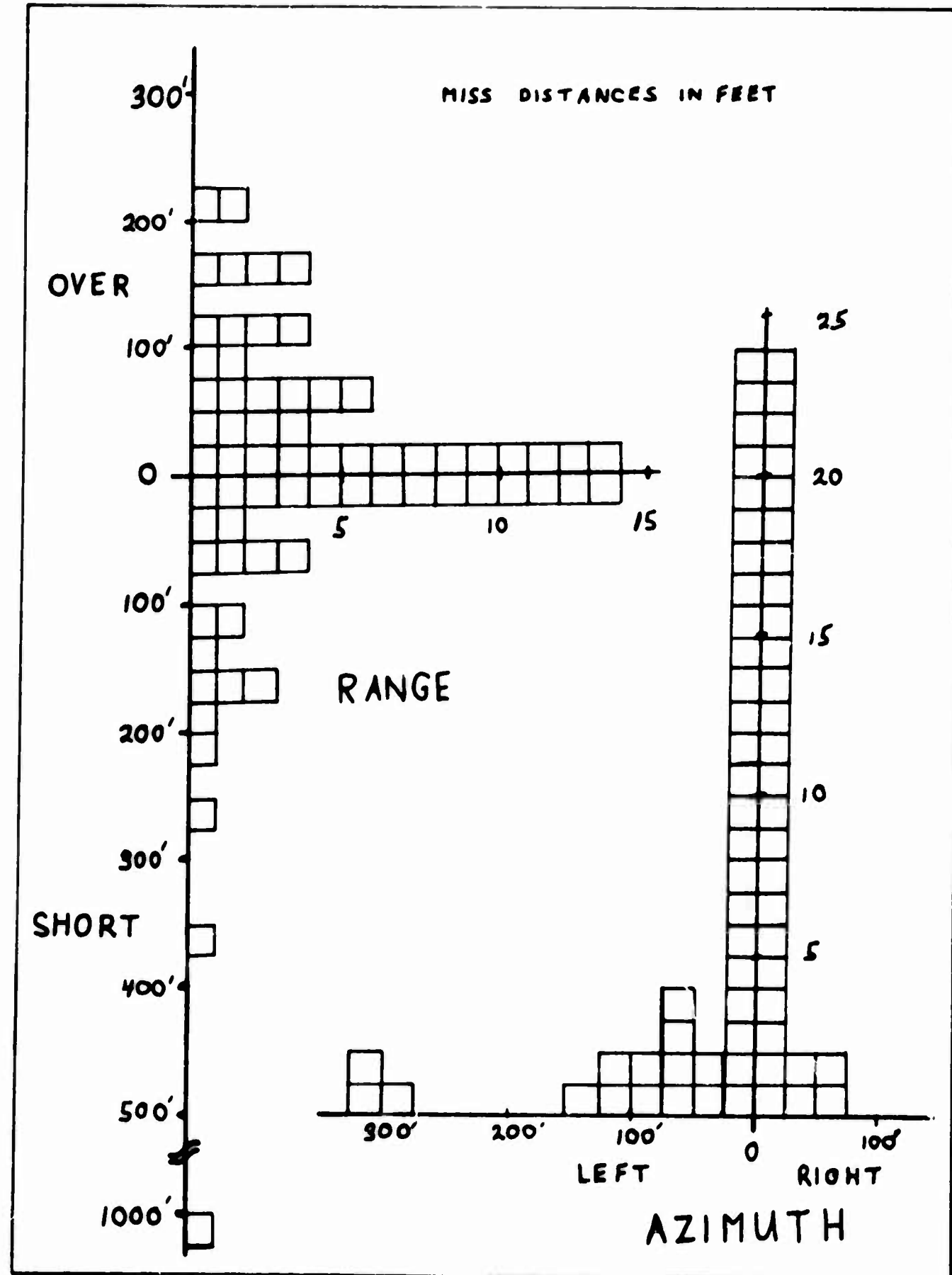


Figure 4. TRAINING OF AZON B-24 BOMBARDIERS
AZIMUTH AND RANGE MISS DISTANCES OF
67 BOMBS CONTROLLED IN AZIMUTH

AZON GUIDED BOMB IN COMBAT (ITALY)

During the period 13 May to 11 August, 1944, the B-17 AZON bombers were engaged in operations with the 15th Air Force in Italy.

This was the period of the Allied offensive to destroy the right wing of the German 10th Army and to drive its remnants and the German 14th Army north of Rome and onwards to the Rimini-Pisa line. Very heavy fighting by the Eighth Army on the right, the Fifth Army to the left, the strong attack by the French Corps across the mountains in the center to cut the Cassion-Formia road, the investment and reduction of the well nigh impregnable Monastery Hill at Cassion, the break out of the VI Corps from the Anzio beachhead, the fighting before Rome and its capture, and the pursuit of the German Armies to the "Gothic Line", constituted a successful campaign with very large forces engaged. The Axis had 412,000 troops in Italy on 1 May including 365,000 Germans. The Allies were numerically somewhat less but had a superiority in artillery and overwhelming strength in the air.

In the context of operations on this scale the exploits of a handful of bombers specially equipped for attacking railway bridges was a small affair which has not been reported in great detail. Their most significant mission was against the Avisio Viaduct on the rail route from the Brenner Pass on 13 May 1944. A message dated 14 May 1944¹⁰, Twining to Eaker, Spaatz, runs: 4 AZON B17 supported by 301 Heavy Bomb Group, 15th Air Force attacked Avisio Viaduct north of Trento on Brenner Pass R. R. 21 x 1000 lb. RDX AZON dropped. Estimated 4 direct hits. Supporting group dropped 1000 lb. GPs simultaneously. Group apparently scored several direct hits on Viaduct and numerous damaging near misses. . . . blocked to all traffic. . . . AZON aircraft led group sighting for range and deflection, remainder of group sighting for range only. Resulting pattern on ground excellent indication of good basic bombing and minimum AZON correction necessary. Bombing from 22,000 feet target altitude 1000 ft.

A cinematic record was made of this mission.¹¹ This has been examined closely and is discussed at some length in the following pages.

A raid on a railway marshalling yard at Oradea, Rumania, by 15th Air Force on 2 June was a complete failure. Because of the spread-out nature of the target the receivers of the 12 AZON bombs (2 each by 6 aircraft) were tuned to the same frequency and all controlled by the leading aircraft. Release was at 22,400 feet. Unfortunately the lead bombardier overshot the main target and no hits were obtained.

By August 11, 15th A. F. had decided that AZON bombs were of no further use to them and handed their stock over to MATAF (B-25). Ira Eaker's message^{10*} to Carl Spaatz is quoted in full: -

Message M27820 Aug. 11, 1944 Eaker to Spaatz
AZON project discontinued by 15th A. F. and is now in
hands of MATAF (B-25).

- (1) Total combat missions flown - 14.
- (2) Total AZON bombs released - 316. 3 missions were ineffective.
- (3) Release of bombs was first done with each aircraft releasing independently (3 missions) with bombs individually controlled.
- (4) On 2 missions bombs were released in salvo and each aircraft controlled its own pattern.
- (5) On 6 missions bombs were salvoed from a 3 ship element with center bomb as guide. The entire pattern was controlled.
- (6) Average altitude of release was 15,000.
- (7) On the earlier missions the aircraft attacked the target singly in line astern. For pattern release and control the aircraft flew in 3 ship element and in 2 element line astern.
- (8) Under individual release and control a deflection correction of 1,340 feet was obtained. Average deflection error for 63 bombs was 605 feet and average range error was 1,600 feet. These figures compare with average errors for normal bombing (15,000 ft. altitude) of 780 ft. deflection and 950 feet range.
- (9) In salvo release and control the average deflection error was 702 feet and average range error was 1,400 feet.
- (10) To date only 2 missions AZON have been flown by TAF and no results have been obtained.

According to this message the bombs which were individually controlled had an average of errors of 605 feet deflection and 1,600 feet range, compared with 780 feet and 950 feet for normal bombs under the same conditions. Errors of AZONs released in salvo were intermediate between the above figures.

The astonishing thing about this message is not the degraded performance of AZON that it indicates but the very large errors referred to for normal bombing from 15,000 feet.

	<u>Errors in Feet</u>	
	<u>Range</u>	<u>Deflection</u>
Normal bombing:		
Proving Ground	169	186
Italian Theater	950	780
AZON bombing:		
Proving Ground	216*	33*
Italian Theater	1600	605
Italian salvo	1400	702

If these figures are to be believed they indicate a severe fall off in the accuracy of normal bombing. This would apply also to the basic aiming of the AZONs prior to release because the AZON range errors are also vastly increased. The explanation also requires an almost complete failure of the AZON control. It had ample steering power to eliminate the azimuth errors latent at release and evidently this was hardly used at all. There is therefore a double failure, firstly to make full use of the Norden bombsight, secondly to use the AZON control. Of course these figures may conceal a bimodal distribution in which a small minority of bombardiers used their equipment correctly but are swamped numerically by the large errors of the others. If this is so one may expect to see signs of it when studying the operations in detail.

Bombing of Avisio Viaduct. 13 May 1944

Unit: AZON B-17 Squadron
 Supported by 301 Heavy Bomb Group
 1st Combat Camera Unit
 Film Reference: AAF 1391

Camera Airplane:

Height 22,000 ft. 21,000 above target
 Camera speed 26.5 frames/sec.
 Focal length 60 mm
 Airplane True Air Speed 246 mph (360 ft/sec)
 Time of fall - 1000 lb GP bombs; 38-39 seconds
 Range to fall - 12,600 feet
 Trail angle at impact - 55 - 70 mil

Film scale - 1 millimeter = 350 feet)
 Drawn as 1 centimeter = 350 feet) = 16.7 mil

(Fuse delay included in time of fall.)

*These are the official Proving Ground figures for AZON quoted in Reference 19. We have not been unable to find the derivation of these figures and they do not agree exactly with any of the particular training examples we have quoted in this report. They are, however, apparently directly comparable with the Proving Ground figures quoted for normal bombing, and probably apply to 15,000 ft altitude.

AZON Bombers

Airplane speed and height assumed to be same as camera aircraft.

Number of bombs reported - 21

Number of bombs seen falling - 9

Number of bombs traced to impact - 4

Number of bombs impacts located but not traced - 13

Number of bombs, no impact seen, apparent dud - 1

Number of bomb impacts counted - 17

Trail angles at impact - minimum 55 mil
- maximum 120 mil

The Avisio Viaduct is on the Brenner Pass railway about 10 miles north of Trento, in northern Italy. The viaduct lies on the left bank of the Adige River and carries the railway over about 3,500 feet of rough ground where the Avisio River joins the Adige. The viaduct is curved. The approach from the south is straight but northwards the curve continues for another 4000 feet or so before the tracks run straight.

Because of the curve the viaduct was not a very suitable target for the AZON guided bomb. The best approach would have been from the south, steering along the tracks and giving the bomb a full right deflection to follow the curve of the viaduct. For other reasons -- and they may have been good ones -- the attack on May 13, 1944 was made from the north along a line which made a tangent with the curve of the viaduct near its northern end. This meant that the bombardiers had no guide line to lead them into the long axis of the target. Consequently they could not control effectively until they could see their bombs in proximity to the curving railway lines. This would have been during the last 8 or 9 seconds of the fall.

The AZONs were dropped in clusters, each aircraft transmitting the same commands to all its bombs. This practice inevitably results in a wide dispersion of all the bombs except the one selected as guide bomb. Therefore only 4 AZONs were significant on this occasion, one from each airplane.

The AZON B-17's were supported by 301 Heavy Bomb Group which dropped a large number of ordinary 1000 lb GP bombs. Their leader followed the AZON bombers over the target and obtained a complete record of the action, at least as far as the fiftieth bomb, with a movie camera trained more or less vertically downward. From this film it is possible to determine much of what happened.

For convenient reference we identify the four AZON bombers as A, B, C, and D. The AZONs are equipped with pyrotechnic flares so that they can be seen by the bombardiers. In the film 9 of these flares can be seen and they segregate into three groups A(3), B(4) and D(2). Four of the flares can be traced

all the way to impact. Five more cannot be seen during the last 4 seconds or so but can be assigned to impact positions when they appear at the right time and place. One of B's bombs seems to have been a dud because there is no impact point in a suitable position beyond where the flare vanishes.

In addition to the bombs traced by their flares another 8 impacts are fairly certainly AZONs. The 18 bombs thus counted enable us to determine the positions of the airplanes in range with respect to the camera airplane. Airplane A is leading 4000 feet ahead followed by B 2500 feet ahead. C and D are only a small distance ahead of the camera, presumably in arrowhead formation with Airplane B.

The camera airplane's own bombs can be seen shortly after release and falling until they are too small to be distinguished. Later, the impacts can be identified. This enables us to establish the line of aim, camera speed and field of view and the scale of distances on the ground. The position of the bomb flares as seen against the ground is of course special to the point of view and what the camera saw is not of course the same as what the AZON bombardiers saw. However, it is possible to estimate the height of the bomb when the time before impact is known, and since the position of the camera is known with fair accuracy this fixed the actual position of the bomb. It is then easy to project the view against the ground from any other position. We have done this for A and B, assuming them to be in line ahead of the camera. It was convenient to use the film as the time base. It was running 26.5 frames per second. We have annotated the diagrams and identified the impacts by film frame number before or after the impact of B's one successful bomb.

Most of the bombs can be assigned with fair certainty to the airplanes which dropped them. The lead airplane A, it seems, loaded 3 only. These can be seen as flares falling. One of them remains close to the original line of aim and impacts at +66 frame overshooting the viaduct by 1500 feet. Another disperses widely to the right. The third cannot be traced with certainty to impact, but may be one on the right at frame +8. An early burst at -49 could conceivably have been one of A's bombs.

B's bombs include 4 whose flares can be seen clearly. One of them deflects far to the right and does not seem to produce a discernible impact. Presumably it is a dud. One other cannot be seen as a flare but its impact is quite definite.

C's and D's bombs together form a large group which cannot with certainty be divided into the two separate groups. On the way down only 2 flares are discernible. One of these can be traced all the way to impact (frame 76). The other came off its bomb and is traced to a flash at impact while the bomb

carries to its impact about 1000 feet farther on. Both of the traces are far to the left of aim and can hardly have been selected as guide bombs. No indication is available as to what, if anything, bombardiers C and D did during the fall of their bombs.

The AZON bomb groups, taken separately or all together, show a prodigious dispersion in both range and azimuth. Regarding B's group, for example, it is almost as though the bombs were so contrived as to steer away from one another for the last 16 seconds of their fall. Impacts #8 and #17 are nearly 1 mile apart in azimuth. The pattern is arrow-headed, with the big azimuth deflections coupled with shorter range and later time of impact. This is a clear confirmation that the azimuth dispersion was accompanied by an increase in drag. Indeed the difference in trail angle between the bombs 23 and 17 and the center bomb 40 is nearly the maximum computed for an AZON controlled all the way and one dropping without control. This suggests that the side bombs had their rudders hard over all the time while the center one had very sparing control application. If this is so, something had gone wrong in the control system.

In A's group bomb #66 has to be explained. It is dead on the aim line and far ahead. The small trio of A's flares when first visible at frame -550 are hard to follow on the film. One of them is traceable to impact at -17, the other two cannot be seen clearly after -200. Up to that time they have the appearance of being controlled because they move from left to right, across the camera's field of view. This, however, could be due to A's aim line not being coincidental with that of the camera aircraft. Most probably flares were clearer to the eye than they are on the film, in which case bombardier A may have been able to see his selected bomb further than we could. Be that as it may, bomb #66 went so far over, and with so little trail, it could have had only the most sparing application of control, or none at all.

In B's and C's combined group there is no evidence of any flare visibility amongst the bombs near the center of the group and no indication that any control was applied.

This leaves us with only B's bomb #0 as a serious candidate for consideration as an AZON bomb properly and rationally guided. Despite its success in getting a direct hit on the viaduct there is little evidence that this was the result of accurate guidance. At this height and viewed with the camera's rather wide angle lens (60 mm on 35 mm film) and with the necessity to project the trajectory to B's viewpoint there was no possibility of detecting the small cyclic movements such as appear very plainly in the contractor's test records. * As we have pointed out there was no sense in applying control to the bomb until its position in respect to the railway could be seen. A slight curvature appears early in the trace. This is maintained as the trace crosses the railway. By this time nothing can be done to improve the chances of a hit

* But if the increase in AZON errors in combat had been due to a large increase in cyclic and aim errors combined, as occurred in the lab stress tests of Appendix 1, these increased cyclic errors would have been detected.

because if the bomb is steered back towards the railway the crossing angle is increased; while steering away will cause a complete miss. Leaving it alone to intersect the curve of the viaduct close to the end gave the highest possibility of a hit. There was insufficient time to give two commands to make the trace follow the line of the viaduct. The question is, did the bombardier appreciate this and do nothing because it was the correct thing to do, or did he just do nothing anyway. Whatever the answer, the hit was a lucky one. At this obliquity the chance of impact occurring while the bomb is passing the viaduct is about 1 in 8.

Whatever may have happened to the AZON bombardiers, there is no doubt that the pilot and cameraman of the camera airplane did their jobs thoroughly and regardless of any threat of interference. The track of the camera follows straight over the target with at most 1 degree of deviation in both pitch and roll. In yaw there is no discernible angular change. This accuracy would result from the Norden's bombsight's ability to stabilize the attitude of the airplane. The lens angle is sufficiently wide for most of the action to be recorded. Most of the damage was done by the regular GP bombs. Two of the airplanes released prematurely and obtained good compact groups about 3500 feet and 5000 feet short of the target. Other bomb loads plastered the target area. A second direct hit on the viaduct, a damaging partial hit and a direct hit on the tracks just south of the viaduct can be seen. Two weeks later another bombardment was made, this time without AZONs. In the photographs of the second raid much of the crater pattern from 13 May can be seen¹². It shows the main concentration at the southern end of the viaduct, some 50-60 bombs within an area 1000 feet wide and 1500 feet long.

It appears that the communique which we quote at the head of this section has to read rather carefully. Everything in it is true. What it does not say is that the direction of attack was not suitable for the AZONs, the clustering of the AZONs deflected them much more than the average uncontrolled bomb; only one AZON bombardier had a good view of his bombs and with a lot of luck got a very good hit. There is insufficient evidence to reveal the state of mind of any of the AZON bombardiers. The evidence from the film is that few flares were visible, the target could not be lined up, and at least two, possibly all four bombardiers, made no attempt to guide their bombs. It seems unlikely that any basis for rational guidance existed on this occasion. The single success attributed to AZON was accidental and insufficiently systematic to be claimed as a credit for AZON used in this way.

AZON GUIDED BOMBS IN COMBAT (NORTHWEST EUROPE)¹⁰

The 8th Air Force used AZONs against bridges in Northern France and Holland from 31 May to 13 September 1944. The 10 x B-24 AZON crews whose training we have examined were diverted to 8th Air Force and flew these missions. At first these men were mixed with operationally experienced crews, later they were reunited in their original crews.

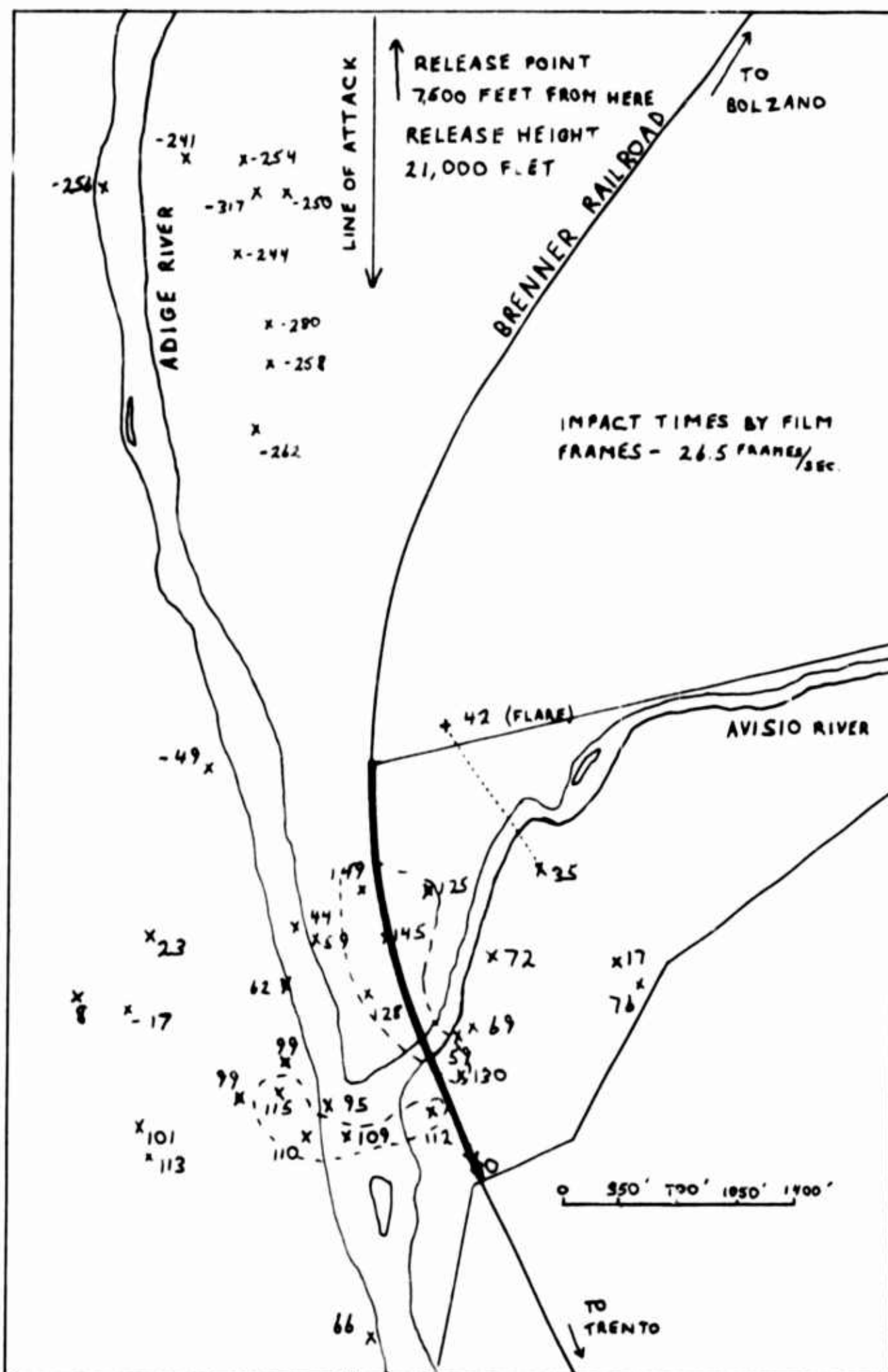


Figure 5. BOMBING OF THE AVISIO VIADUCT, MAY 13 1944 - FIRST 38 BOMBS

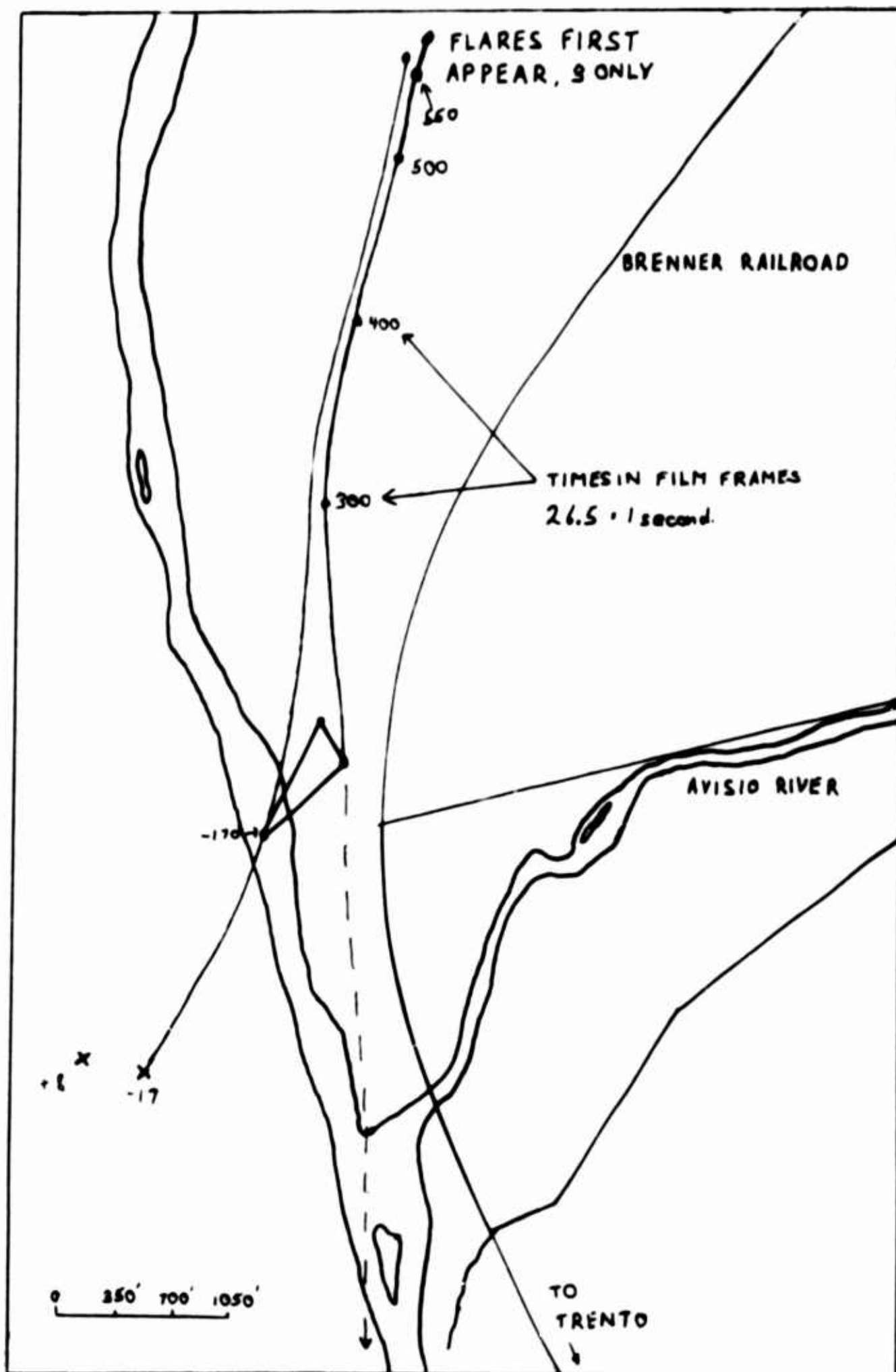


Figure 6. BOMBARDIER A's VIEW OF HIS BOMBS - AVISIO VIADUCT

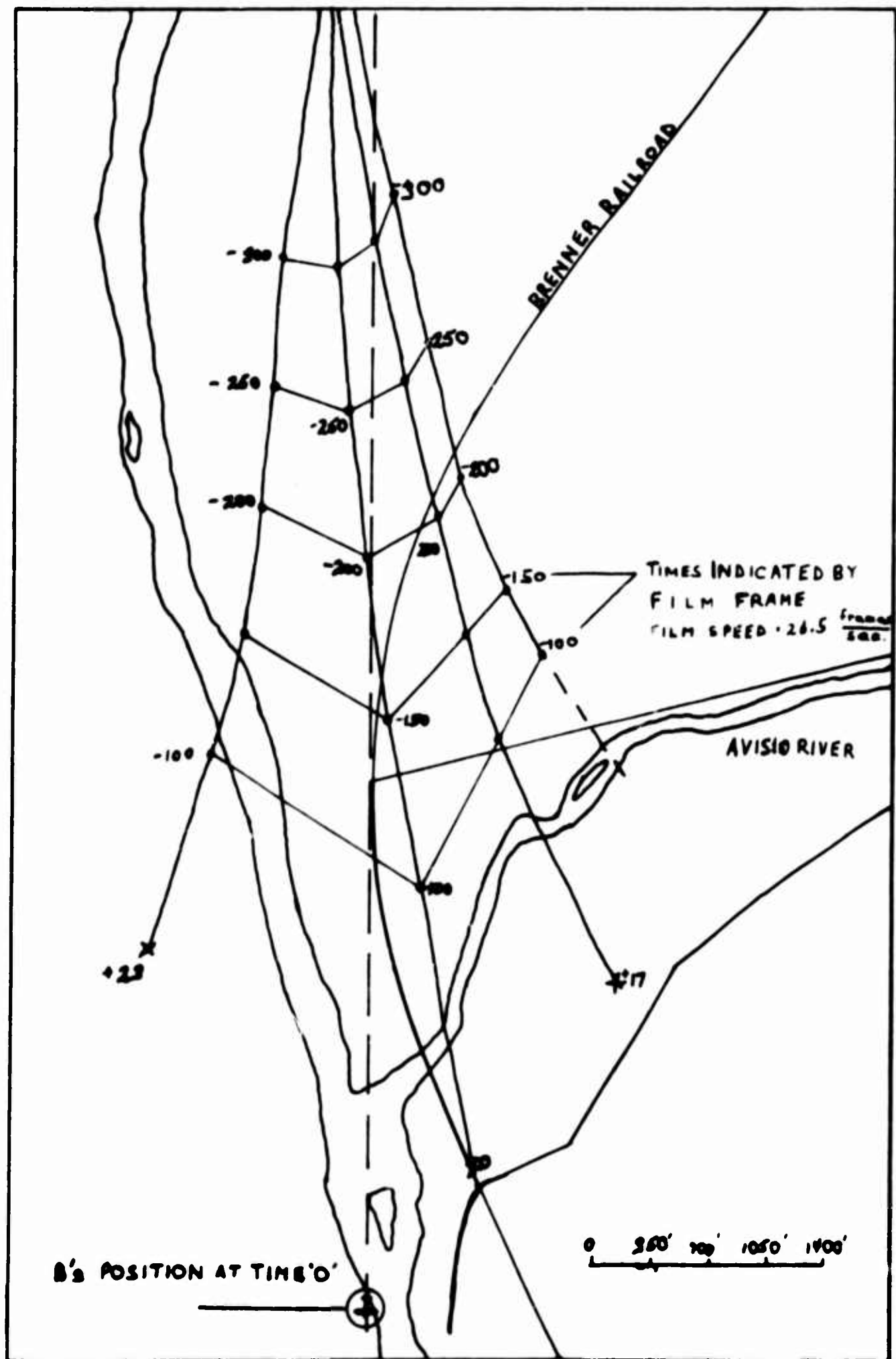


Figure 7. BOMBARDIER B's VIEW OF HIS BOMBS - AVISIO VIADUCT

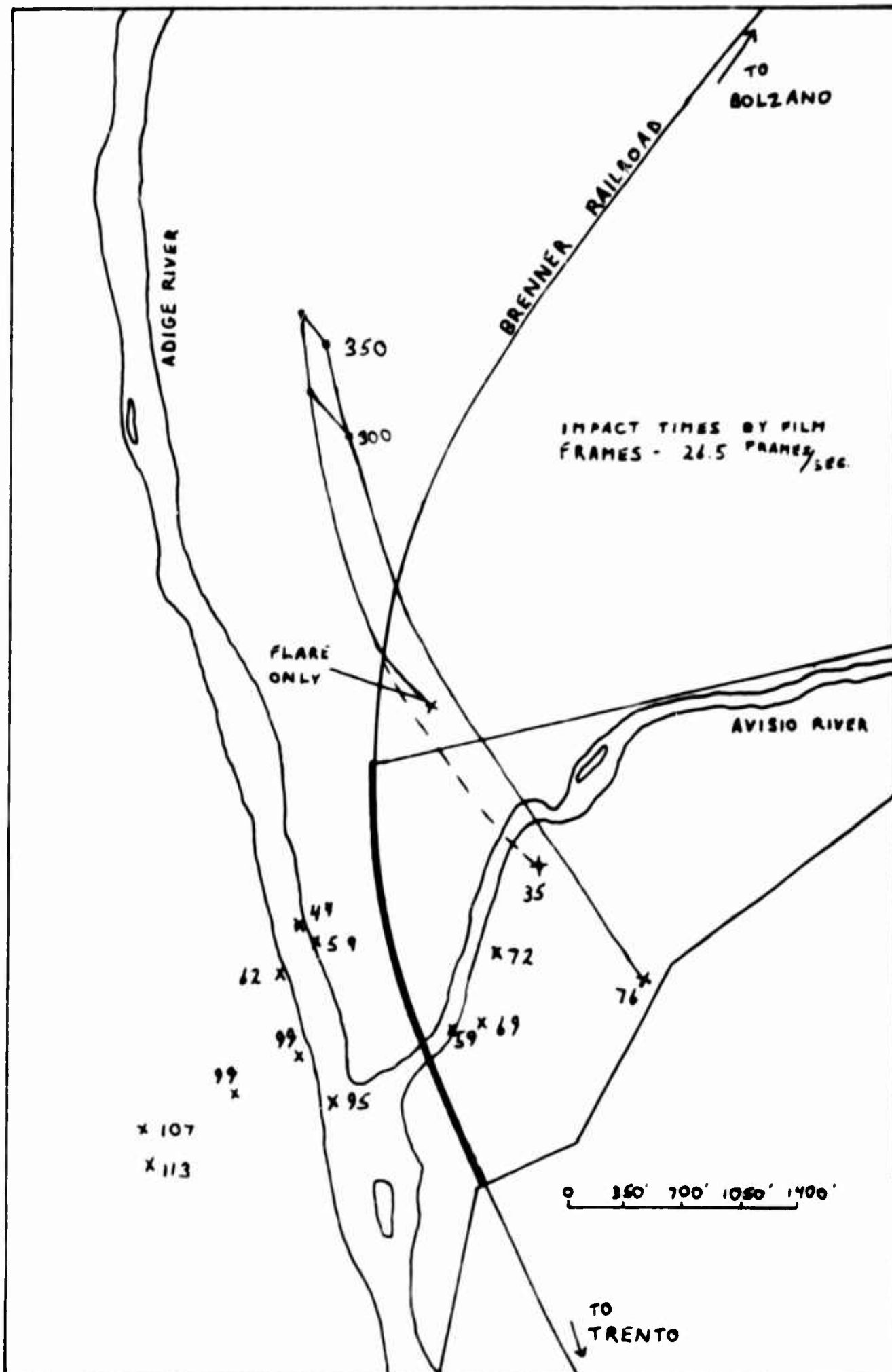


Figure 8. IMPACT POSITIONS OF C's and D's BOMBS

We have a complete list of the missions flown, though not in the kind of detail needed for assessment of control accuracy. They were as follows:

(1) 31 May 1944

1.1 Railway bridge at Paris
90 x 250' long

4 bombs 1 in river near bridge
 1 near entrance to bridge
 1 on tracks at far side
 1 hit 100 feet from target

1.2 Melan bridge embankment
5300 feet long

No bombs, cloud obscured target

1.3 Verberie bridge
300 feet long

2 bombs 1 short of target
 1 300 feet southeast of target

1.4 Suspension bridge at Precy
350 feet long

4 bombs 1 hit at north end
 1 just over
 1 100 feet over
 1 300 feet over

1.5 Bridge at Beaumont-sur-Aire
300 feet long

3 bombs 1 hit island in middle of river
 1 hit tracks just short
 1 hit tracks at end of bridge

Total 13 bombs dropped, individually controlled. Remaining
7 bombs brought back to base.

(2) 4 June

2.1 Melun bridge embankment
5300 feet long

13 bombs dropped from 15,000 feet

8 bombs controlled
PRU Report - 50% within 500 feet radius
- 67% within 1000 feet radius
- 100% within 2000 feet radius

(3) and

(4) 8 June

Melun bridge embankment

No bombs dropped, target covered by cloud.

(5) 14 June

6 bridges attacked

20 bombs, 14 controlled, no record of result.

(6) 15 June

Same as preceding

27 bombs, 20 controlled, no record of result

(7) 22 June

Graumer railway bridge
3600 feet long

11 bombs dropped, 9 recorded
PRU Report - 3 within 500 ft.
4 within 1000 ft.
8 within 2000 ft.

Tours le Riche Railway Bridge
1100 feet long

Remainder of bomb load (total 36 bombs)

(8) 17 August

Rail bridge

No bombs, target covered by cloud.

(9) 25 August

9.1 Moerdyck railway bridge - see Figure 2
3400 feet long

9.2 Tours le Riche bridge
1100 feet long

50 bombs, 32 controlled, no record.
(We have seen a photograph showing at
least 1 hit on this bridge.)

(10) 26 August

Moerdyck bridge

No bombs, target covered by cloud.

(11) 1 September

Ronestein railway bridge

24 bombs, 20 controlled, no record.

(12) 5 September

Railway bridge

No bombs, mission recalled due to weather.

(13) 13 September

Oil refinery at Flensburg

55 bombs dropped, 25 controlled.

The attack on Moerdyck bridge illustrates the practice of dropping AZON in clusters, all bombs receiving the single set of commands from the parent aircraft. This was adopted in the hope of increasing the effectiveness of AZON in a single run over the target rather than expose the aircraft to the hazard inherent in repeated runs for individually controlled drops.

Figure 9 is a composite of 2 photographs taken during the run. Five aircraft were in V formation, the lead aircraft dropping 4 uncontrolled GP bombs and each of the wing aircraft dropping 4 AZONs in a cluster. The first picture shows 3 of the AZON clusters about half way down; the second shows their impacts, together with those of the lead aircraft's unguided bombs.

The unguided bombs show a compact group about 200 feet across, missing the bridge by about 200 feet. This is good standard bombing, but is ineffective against a narrow line target.

The three AZON groups show wider dispersion, about 500 feet, which is to be expected because of the roll stabilization. One cluster, marked as #3, was evidently not controlled (due to failure of radio equipment or the operator himself) during the descent. The other two clusters are spread across the line of the target with their centers very near to it, in fact one is evidently a direct hit. It is fairly obvious that only the bomb nearest the center of the cluster, as determined by the bombardier, stands a typically AZON-like chance of hitting because the dispersion of the others is relatively large, up to 250 feet or so either side. The slave 'wingers' in the group stand absolutely no chance of hitting if the center is well controlled and would only increase the odds when the control was very poor.

Because of this ineffectiveness the bombardier's skill is properly indicated by the miss distance of the group center and we therefore feel justified in counting clusters as single bombs when estimating his performance.

Air Force commanders were well aware of the nullifying effect of AZON dispersion when dropped in clusters and instigated serious attempts to reduce it by actually tying the bombs together with wire or cable as recounted in their final report. This however was to prove technically too difficult an adaptation to be carried out "in the field".

Summary AZON attacks on bridges - NW Europe (1944)

<u>Mission</u>	<u>No.</u>	<u>Bombs</u>		<u>Hits and damage</u>	<u>Bombs/ Hit</u>
31 May	1.1	4	Individual control	1	4
31 May	1.3	2	" "	0	above 2
31 May	1.4	4	" "	2	2
31 May	1.5	3	" "	2	1.5
4 June	2.1	8	" "	No record	
14 June	5.	14	" "	" "	
15 June	6.	20	" "	" "	
22 June	7.1	11		0	above 11
22 June	7.2	25		0	above 25
25 August	9.	12	Bombs in groups of 4	1	3
1 Sept.	11.	20	" " " " "	1	5

On 25 August and 1 September the AZONs were controlled in clusters of 4. As far as the result is a measure of the bombardier's skill these should be counted as single bombs. Although the evidence is skimpy it shows quite clearly that on five occasions the result was that one bomb per 1.5 to 5 bombs hit its narrow target. On another four occasions the result is indeterminate and on the remaining two occasions the performance was poor if the bombs were controlled in clusters, and very poor if they were controlled individually.

A comment from Headquarters, 8th Air Force says: "Technically speaking, AZON is good when we refer to average bombing where 30-35% hit within 500 feet."

This is faint praise when we remember that the accuracy demonstrated in training and observe that on five of the combat occasions the results were quite up to the training standard. With the exception of No. 13, the targets on all these missions seem to have been suitable for AZON attack. Much care seems to have been taken not to drop the AZONs when conditions over the targets were unsuitable, and apart from the clustering the weapon appears to have been fairly and properly used. On five occasions operational degradation was apparently nil. On some other occasions it was apparently severe.

The final report on these operations is reproduced in full. It is of little help in assessing accuracy but it does confirm that this was thought to be a good weapon when properly used, even though its continued use in this theater was not justified.

HEADQUARTERS
EIGHTH AIR FORCE
Office of the Commanding General
APO 634

E-D-55

*By authority of CG, 8th *
*Air Force. *
*Initials: L. J. Z. *
*Date: 31 Oct 1944 *

SUBJECT: Report of AZON operations.

TO: Commanding General United States
Strategic Air Forces in Europe, APO 633

DECLASSIFIED BY DOD
Dir. 5200-9

1. One (1) squadron of the Eighth Air Force was assigned the project of making operational tests with Azon bombs. Operational experiments with Azon equipment after the completion of thirteen (13) operational missions, data on which is attached, produced the following results:

- a. Azon equipment was found to be satisfactory and proved that this type of weapon properly employed would be effective.
- b. It is believed that, for the successful employment of Azon, target weather must be clear. Cloud conditions of more than two to four-tenths (2 to 4/10) stratus or strato-cumulus preclude the use of this weapon, because any cloud coming between control airplane and the bomb prevents proper guidance of the missile. It is here pointed out that clear weather is rare in this theater.
- c. During the period of these operations a constant state of alert, with very few resulting missions, caused an unfavorable state of morale amongst the crews. This state of alert was necessary in order to take advantage of any breaks in weather which might occur.
- d. The limit of availability of control stabilizers made practice missions negligible. Consequently, the Azon equipped aircraft, the crew technical specialists and other highly trained personnel could not be utilized to the best advantage of the war effort.
- e. It has been proven in the course of these experiments that regular strategic precision pattern bombing could do any tasks so far assigned to the Azon squadron.

2. It was necessary before the above operations commenced to train crews in the handling and operation of this weapon. At the beginning of the Azon experiments, the squadron assigned this project had three (3) crews in category "A" trained as lead crews, who were proven in combat and had led the group, three (3) crews in category "B", and all other crews of the squadron were regular combat crews. Ten (10) new crews of the squadron were received from the United States who had been especially trained for Azon bombing. The bombardiers were proficient in target recognition and map reading, and no difficulty was

experienced in this respect. Every effort was made to develop teamwork between the pilot, navigator and bombardier. Pilots and navigators were assigned permanently to the lead crews. When the ten (10) special Azon crews were received from the United States, the pilots were flown as co-pilots with the lead crews, and the Azon bombardiers were used on the lead ships. Later the special Azon crews were reassembled as lead crews after having gained some experience flying with the proven lead crews.

3. Techniques used on Azon missions were as follows:

- a. On missions Number 1 and 2, aircraft were flown in trail, each bombardier sighting and controlling individually.
- b. On missions Number 3, 4, and 5, the lead aircraft made a regular sighting, the wing ships sighting for range only and each ship controlling individually.
- c. On missions Number 6 through 13, all aircraft dropped on the lead ship and controlled individually.
- d. An attempt was made to splice the Azon bombs together with wire and cable, but in most cases they broke apart before reaching the target. Heavier cable could not be used because it was necessary to tie the cable to the nose fuses.

4. It is believed that the weather expectancies in this theater and bombing results obtained on these experimental missions justify the following recommendations:

- a. The Azon bombing project be discontinued in this theater.
- b. Azon equipment now assigned to the group which has been conducting these experiments be released to that unit to be utilized as radio bomb release equipment.

For the Commanding General:

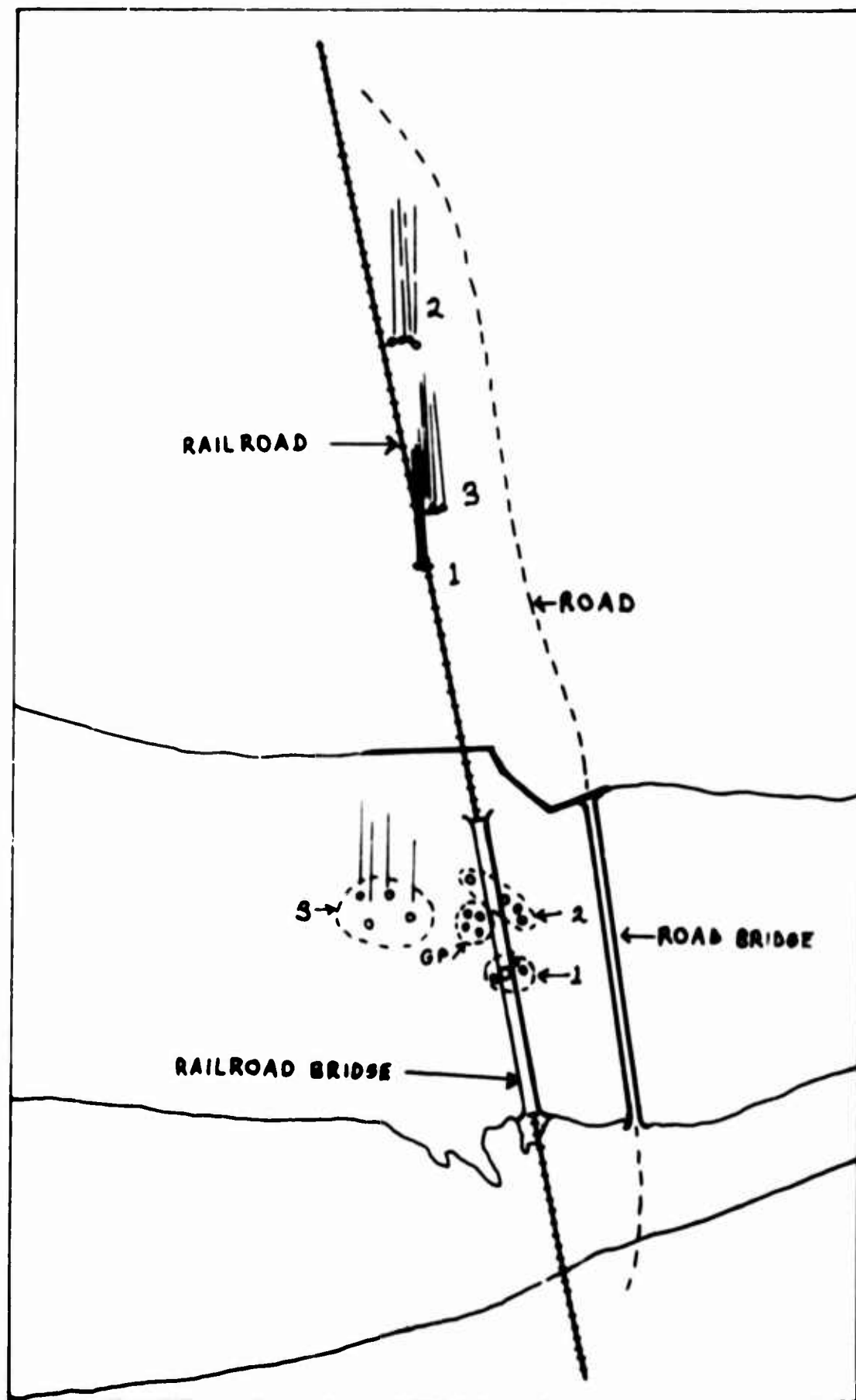


Figure 9. ATTACK ON BRIDGE AT MOERDYCK

AZON GUIDED BOMB IN COMBAT (BURMA)

During the course of 1944 the pattern of the war in Burma changed to the advantage of the Allies. The Japanese remained in occupancy of most of its vast territory without air power and dependent upon surface communication for the movement of supplies. The winning formula for the Allies was the operation of large independent land forces supplied wholly by air. The air bases were in India, supporting ground operations in Assam and over in Burma eastwards across the Arakan mountains.

To the 7th Bombardment Group, nominally 10th Air Force, operationally part of Strategic Air Force in that area, there was nothing special about the AZON B-24's when they arrived in late September, 1944. Reports from Italy had not been good, airplanes were badly needed for other purposes, and so the AZON tails and transmitters which they had brought were unloaded and dumped in storage buildings and the airplanes were distributed amongst the four squadrons of the Group. The AZON maintenance officer, who had arrived a few weeks earlier from Fort Dix, New Jersey, had a hard time trying to collect more tails from Calcutta and, above all, the vital test equipment which somehow had been overlooked and had to be reconsigned from Fort Dix. Thus, nothing happened to bring AZON into its special use against the Japanese rail bridges. Meanwhile, 2 of the B-24's were lost in other operations and 5 were put on to the Hump Air Line, hauling gasoline into China.

On December 10, 1944, Major William Donics* and Dr. T. J. O'Donnell** (of Gulf) respectively the NRDC officer and technical observer on the AZON project, arrived on special assignment to Headquarters, 10th Air Force. They had with them films and test data showing the merits of AZON and they convinced the commanders that this was something worthwhile. Even so they got no priority but by various efforts they had the 5 airplanes recalled from China and were ready for operations by December 27.

The first target was the bridge at Pyinmana on the Rangoon-Mandalay railway. Three of the B-24's flew this mission. Each of the bombardiers was allowed one practice bomb on the railway lines on the way to the target.

The target was perfect for AZON, having a straight approach of rail lines and being sufficiently long (380 feet in three steel spans) to accommodate all the prospective errors of range. 9 AZONs were dropped, one each by each airplane in 3 passes. 3 hits were observed. This result is consistent with the training result of their predecessors at Eglin. The bridge will have

* Now Colonel, USAF, Deputy Chief of Staff (Logistics)

Headquarters, Air Force Communications Service, Scott Field, Illinois

** Now Coordinator, Gulf Research and Development Company, Pittsburgh, Pa.

been about 18 feet wide and a hit means a deflection of 10 feet or less. The bombing height was 9,000 feet so 1 in 3 fell within \pm 1.1 mil. In training, 1 in 2 fell within \pm 1.5 mil. Degradation was nil on this occasion.

The report says that neither Flak nor enemy aircraft was sighted. This was fairly usual at this time in this theater. The Japanese attempted to defend their bridges but were very short of heavy ack-ack ammunition and relied chiefly on light cannon, machine guns and small arms. At 9,000 feet the bombers were out of range, and the crews may have felt quite comfortable about the operation and have had no cause to do worse than when in training.

Three days later the AZON aircraft attacked the road leading from Prome, in the Irrawaddy valley to Taungup on the coast road. They attacked bridges at Nyaungchidank and Okshitpin, near Prome, and at Taungup.

We have cinematic film record of these drops, taken by one of the attacking aircraft, and have transcribed from it the traces of the bombs as seen against the ground. On this occasion, unfortunately for our analysis, the targets were all road bridges lacking straight approaches. The bombardiers, having no ground reference lines, appear to have guided their bombs along the airplanes' ground tracks until the target appeared in view and then to have made their best to steer towards them. In this they were only slightly effective.

Looking at the 11 best bombs of this set, the following conclusions may be drawn:

1. The cyclic errors were very small (7.35 feet mean).
2. The aim errors were large. From these alone the standard deviation is 81 feet. The median deviation is 55 feet and is about the mean 14 feet right of target. From this evidence taken prior to the actual impacts 50% of these bombs can be expected to impact within the median and since the mean aim error, or bias, is comparatively small (14 feet), this is practically the same as saying that 50% were due to impact within 55 feet right or left of the target.

However, the actual impacts reveal that 8 of these 11 bombs fell within 55 feet of the target, implying that 50% fell within about 35 feet. This improvement is too large to be due to the random effect of the cyclic errors, even in the most lucky combination. We may suppose that the bombardiers' efforts to guide the bomb just before impact were partially successful.

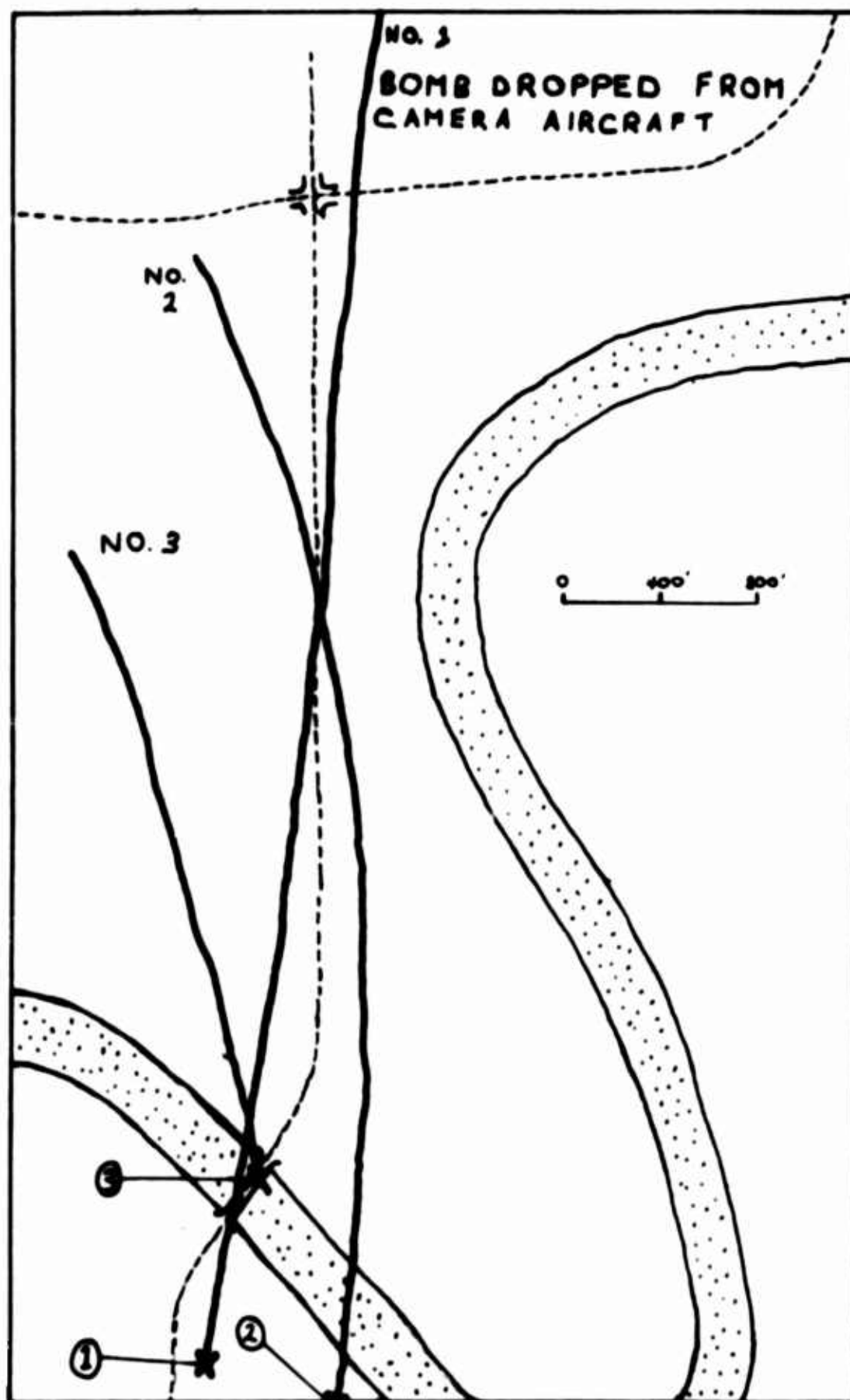


Figure 11. ATTACK ON OKSHITPIN BRIDGE

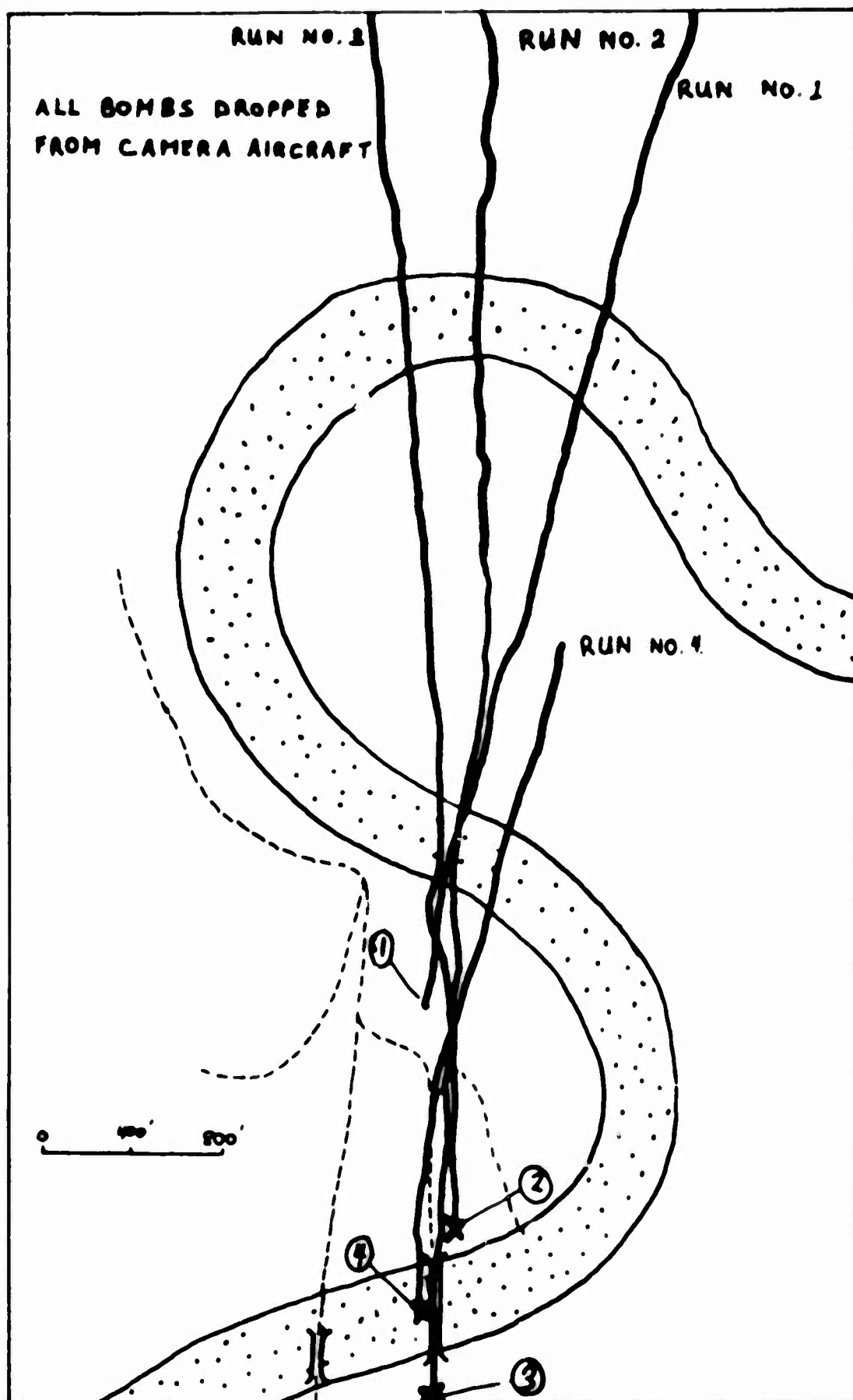


Figure 10. ATTACK ON NYAUNCHIDANK BRIDGES

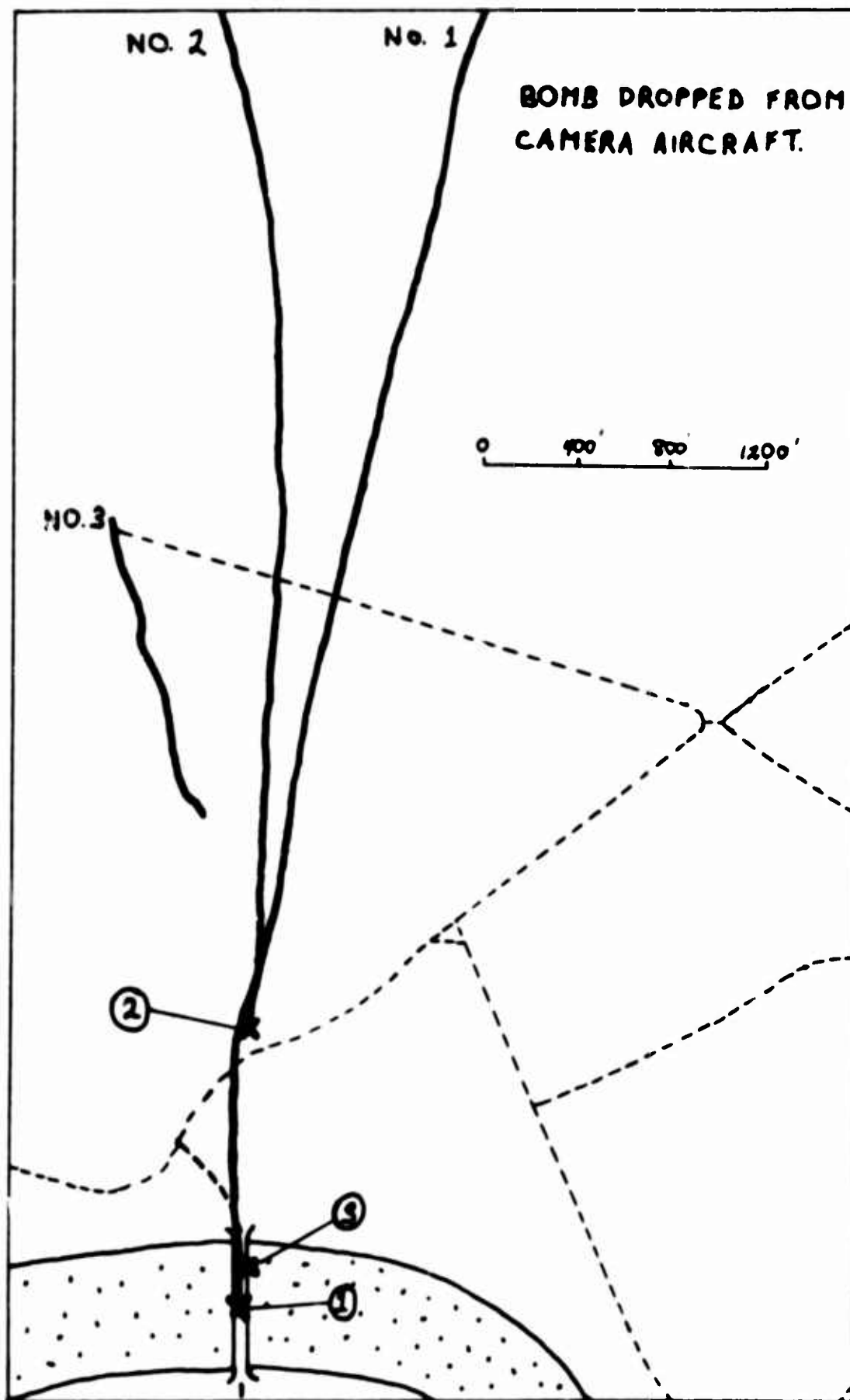


Figure 12. ATTACK ON TAUNGUP BRIDGE

Even so, a median miss distance of 35 feet is poor in comparison with the 12 feet or so in the training runs. We note also that these 11 bombs had large errors in range, something like 200 feet compared with 60 feet in training. Thus the evidence suggests a threefold increase in both deflection and range. The story is even worse if we include all the bombs dropped on this occasion. According to the report, 28 AZONs were dropped in the day's attacks on these bridges. Taking all of these into account the best that can be said is that $11/28 \times 1/2$ would have hit targets 70 feet wide by 400 feet long.

That is, 3 bombs out of 28 hit 400 x 70 feet. Actually 4 bombs hit within this area.

Although this analysis is necessarily rough, it indicates an error increase of 3 times in this day's work despite the clear indication that the bombardiers could steer their bombs as accurately along a given straight line as shown in the training. But on this occasion, there were no given straight lines. Thus, the degradation seems to have been due to misuse (technologically) of the weapon. There is no obvious explanation of the increase in range errors.

Of course, the mission was a success. The hit all of the bridges and closed the road.

AZON was used diligently as the Allied offensive continued. The Japanese were dependent on the railways from Siam and Malaya to Rangoon and northwards to Mandalay, and Eastern Air Command attacked the bridges unremittingly mainly with AZON but additionally with ordinary GP bombs. We have a complete list of these missions beginning on 1 November, 1944 before the AZONs arrived and continuing to 5 March 1945, by which time the Japanese resistance was contained in pockets without supplies from outside.

In the period 27 December 1944 to 5 March 1945, 7th Bombardment Group "expended 459 AZON bombs, resulting in the destruction of 27 bridges." (We are quoting the Group Bombardier's report.) "During this period an average range error of 201 feet and an average deflection error of 131 feet has been maintained. Ten to fifteen percent of the bombs dropped have been direct hits, the bridges averaging approximately 250 feet in length. These accuracy figures do not include those dropped as standard bombs, nor malfunctions or gross errors from heavy undercast."

It is not clear how the average errors are derived. We have been able only to quote hits, direct hits or damaging, from the operational summary, and these are reported in Table 3.

TABLE 2. Summary of operations by 493 (AZON) Squadron, 7th Bombardment Group
November 1944 - March 1945

Date	Target	Size (ft)	No. of Bombs		Hits		Bombs per hit	
			GP	AZON	GP	AZON	GP	AZON
1 Nov	RR Br.	780 x 18	6	-	1 poss.	-	6	-
5 Nov	Tunnels		10	-	0	-	10	-
23 Nov	RR Br.	500	72	-	0	-	72	-
26 Nov	RR Br.	320	35	-	1	-	35	-
26 Nov	RR Br.	770	54	-	0	-	54	-
27 Dec	RR Br.	380 x 14	21	9	0	3	3	3
30 Dec	Road Br.	75 - 400		28		4		7
1 Jan	2 RR Br.	200 x 15 210 x 14	10	16	0	0	10 above 16	
3 Jan	RR Br.	11400 x 14	6	11	0	1 ?	64	11 ?
3 Jan	2 RR Br.	-	2	5	0	0	2 above 5	
8 Jan	RR Br.	-	0	17	-	2	-	8.5
8 Jan	RR Br.	-	0	9	-	3	-	3
8 Jan	RR Br.	-	0	3	-	0	- above 3	
8 Jan	RR Br.	-	0	1	-	0	- "	1
9 Jan	RR Br.	-	6	6	2	2	3	3
9 Jan	RR Br.	-	4	5	1	2	4	2.5
9 Jan	RR Br.	-	2	1	0	0	3	(salvo)
11 Jan	RR Br.	450	1	9	1	8	1	1.12
11 Jan	RR Br.	-	13	15	2	8	7.5	1.19
13 Jan	Jetty	1350 x 450	0	15	-	1	-	15
27 Jan	RR Br.	430	0	18	-	6	-	3
27 Jan	RR Br.		0	18	-	3	-	6
3 Feb	RR Br.	360 x 15	0	16	-	3	-	5.3
5 Feb	RR Br.	360 x 15	0	12	-	1	-	12
7 Feb	RR Br.	740 x 16	24	24	Multiple		Few	Few
9 Feb	RR Viaduct	1230	24	18	2 Caps		Indeterminate	
11 Feb	RR Br.	500	0	18	-	4	-	4.5
11 Feb	RR Br.	150	6	9	0	-	6	-
15 Feb	RR Br.	260 x 15	12	24	0	2	12	12
21 Feb	RR Br.	500 x 16	11	21	0	3	11	7
23 Feb	RR Br.	300 x 15	0	6	-	2	-	3
25 Feb	RR Br.	400	48	0	6 or 8	-	7	-
27 Feb	RR Br.	430	0	18	-	4	-	4.5
3 Mar	RR Br.	800 x 16	0	24	-	1	-	24
3 Mar	RR Br.	740 x 16	48	0	2	-	24	-
5 Mar	RR Br.	280	36	36	Damage	7	36	5.1
Totals	30 Bridges	-	226	361	18	50	12.5	7.2
					approx.	approx.		

It is not clear how the averages for the errors are computed. A figure of 131 feet for the average deflection does not suggest that it should include ten to fifteen percent of direct hits unless on targets 18 feet wide it also includes a number of very wide misses.

This appears to be the case. Looking at the tabulated results of all the operations we see a considerable fraction which qualify as equal to the training results in the number of bombs per hit. The rest are very much worse. This is similar to our findings for the operations in Northwest Europe and leads to the conclusion that the distribution of error is bimodal, that AZON in combat either worked as it did during training exercises or it hardly worked at all. There is no evidence as to why this dichotomy should have existed, certainly none to say that it was due to effective enemy intervention at any rate in Burma. Where we have detailed information poor results are attributable to unsuitability of the targets.

The table is quite remarkable for the evidence it shows of improvement in the accuracy of the unguided bombing after the beginning of the AZON missions. The figures for number of bomb hits are far too good for unguided bombing from 9,000 feet on many of the occasions and the overall average figure of 12.5 is much better than can be expected, certainly better than proving ground results. We understand that the improvement was due to two factors*. After their successes the AZON crews were very pleased with themselves. This set up a rivalry between their squadron and the other three in the group. The second factor was the waning of the enemy opposition, which enabled the "standard bomb" aircraft to adopt a very low level glide attacks on some of the missions (as low as 1,000 feet.) The stringency of the military situation was relaxing considerably during the period of these operations and the campaign was practically over by the time they ended.

DISCUSSION OF RESULTS OF FILM ANALYSIS

The accuracy of the AZON Bomb as predicted in Appendix 1 agrees well with the results measured at the Proving Ground, but the combat results showed that the miss-distance was greatly increased in battle.

A direct analysis of the oscillatory component of the tracking error could only be made in two cases: the attacks on the road bridges in Burma and the attack on the Avisio Viaduct in Italy. The results show:

- a. No increase in the oscillatory component (Burma) but an excessive "aim" error.
- b. No discernible oscillatory component, but large errors in impact. (Avisio)

* From conversation with Colonel Hugh D. Wallace, now Director of Collection, AFCIN (Pentagon), formerly Deputy Commander, 7th Bombardment Group.

Conditions in the first theater (Burma) were easy, with no immediate enemy threat. However, the target was unsuitable for AZON since there was no straight aim line to the target. (We would expect that, if suitable 'combat' type training has been given, more last minute corrections would have been made to the flight path.) Hence, we may conclude that in light combat there is no evidence of any combat stress, though there is still considerable operational degradation against unsuitable or hidden targets.

In the Avisio test combat conditions were very severe. The Germans had large numbers of 88 mm guns mounted along the gorge through which the attack was made and the attacks were made by F. W. 190 fighters. We know that these attacks on the Avisio Viaduct were considered to be very dangerous and only justified by the importance of the target. Under these circumstances there is very little evidence of control to be seen on the films and no evidence of last minute corrections, although the miss-distances are very large indeed. If these large miss-distances were due to stress degradation of the type reported in Appendix 1 we could have expected to see a very large oscillatory error about the mean path. No such oscillation was observed. Possible alternative conclusions are:

1. The large degradation in aim was not accompanied by any increase in oscillatory error. This would imply that the bombardier continued to operate the stick mechanically at the same or higher frequency as he used in training but without making any conscious effort to direct the bomb to the target. This would presumably imply a large stress effect but not of the type observed in the laboratory.
2. The radio control failed. But this would mean that it would have to fail in every one of the AZON bombs studied in this attack.
3. The equipment reliability was so bad that the bombardiers had no confidence in the controls, and did nothing. We know that complaints were made about unreliable bombs but the general impression is that the failures were only of the order of 30%.
4. The bombardiers would select his best bomb out of his cluster of four and give it one or two long bursts of control to line it up with the target during the early part of the flight. He would then abandon control and permit the pilot to take evasive action as desired.

The latter explanation seems by far the most likely. It explains the increased range error relative to normal bombing and the appreciably reduced deviation error. It also explains the enormous increase in error relative to the Proving Ground results where the bombardier controlled the AZON all the way to the ground.

This, of course, is pure speculation since we were unable to find and interrogate any of the bombardiers who took part in the Avisio raid. However, we do know that opposition was intense, that severe degradation occurred even with the ordinary bombsight which should be easier to handle, and the AZON crews resented the fact that they had to continue their bombing run for thirty seconds or so longer than the Norden bombardiers.

We may certainly conclude that any future missile system utilizing human operator should include provision for observing and recording results including the operators control movements.

DISCUSSION OF RESULTS OF MISS-DISTANCE ANALYSIS

AZON bombing on the average deteriorated in accuracy from proving ground figures in combat. In some cases studied (Avisio, Taungup) the system was used improperly and there was no possibility of achieving proving ground accuracy. The practice of releasing in salvo (clusters) spoiled figures for accuracy when this was expressed as hits per bomb or average miss-distance per bomb. Only one bomb of the salvo should be considered. When this is done figures for hits per bomb improve. Combat results for AZON shows a wide variability ranging from the equal of proving ground figures to immeasurably poor. The best results occurred in Burma, where enemy opposition was light, where the AZON project officer and observer were present on special assignment and where the majority of targets attacked were suitable to the AZON system. Even so, after the first very good attacks, the special observers left, and the performance deteriorated. For all missions in Burma the average error was considerably greater than that achieved during training.

The figures from Northwest Europe range from the equal of the accuracy on the training range to appreciably worse. Apart from the practice of dropping the bombs in clusters the system appears to have been used carefully against targets that were suitable for it, and under conditions of adequate visibility. According to the final communique this care resulted in a constant state of morale amongst the crews. Some part of the reduction in accuracy may be attributed to this, but even so there is an obvious degradation.

The poorest result is from Italy where enemy opposition was strongest and the figures overall are little different from the average figures for unguided bombing in combat. On the one operation that has been studied closely in this investigation from the direction chosen for the attack the target was not

suitable for the correct operation of AZON, but even so there is no indication that any serious attempt was made to guide the bombs during their fall. Despite a lucky hit, the AZONs were less effective than an equal load of unguided bombs would have been. In this case, however, the deflection errors of the AZON bombs are increased by a factor of over 18 as compared with increase of deflection errors for normal bombing under these conditions of 4.2.

There is no evidence to indicate the mental or physical condition of any of the participants on any particular occasion.

COMPARISON WITH RESULTS OF GERMAN GUIDED BOMBS

The AZON results suggest that severe degradation of the accuracy of such a bombing system occurs under conditions of heavy combat. This is supported by a consideration of the results on two German Guided bombs employed against the British Fleet at about the same time. Somewhat fragmentary information on these bombs, the FX 1400 and the HS 293, is given in Reference 15 and is discussed in detail in the main report Reference 16.

The FX 1400 was a high angle bomb dropped from an altitude of about 1500 feet against heavy units of the British Fleet, against no doubt intense opposition from anti-aircraft gunfire and the strong probability of attacks from carrier borne fighters. However, on the average conditions were probably somewhat less severe than in the attack of the Avisio Viaduct as the concentration of gunfire would have been less. Owing to the nature of the target the important errors would be restricted to the lateral plane of the target and the control characteristics of the bomb were in fact very similar to AZON. Reference 16 concludes that the training errors were increased by a factor of 6.6 under these combat conditions.

The HS 293 was a long range glide bomb employed in beam attacks against light units of the fleet, and we may conclude that combat conditions would be much less severe in this case. The control task was probably appreciably simpler since such a bomb has a rather rapid response in pitch the critical dimension. Reference 16 quotes an overall combat degradation factor of 2.3 for this case.

The results for the German bombs, therefore, fall between the extremes measured for AZON and it is unfortunate that the time allowed for this investigation did not permit us to obtain the combat films for these missiles which are known to exist. It would be most interesting at some future date to obtain these films and make a direct determination of the combat degradation of the German crews. Such a determination will be particularly interesting since we know that the same squadron was used in development work, combat training and combat for each bomb.

CONCLUSIONS AND RECOMMENDATIONS

The general conclusion of AZON is that there was severe degradation of the system when it was technically misused (operational degradation) but that degradation also occurred with highly suitable targets. In isolated instances involving no opposition there was no degradation at all. The worst results are from where the opposition was strongest and in this case even after allowing for a factor of two for operational degradation there is still a factor of nine to be accounted for which may well be due to combat stress under severe conditions.

The film analysis is unfortunately only available for two extreme cases and gives no apparent degradation of control function under conditions of no opposition and an apparent abandonment of control against strong opposition.

These remarks should be supplemented by the results of official analysis of combat in Burma. Apparently this report is still a classified document and it is discussed in the main report¹⁶ of this contract.

Results for two German guided bombs support the conclusion that there is probably a regular degradation of operator performance with increasing severity of combat conditions. This conclusion agrees with the main report.

The authors recommend that the German combat films for HS 293 and FX 1400 should be procured and studied for evidence of severe combat degradation without complete loss abandonment of control.

ACKNOWLEDGMENTS

The authors wish to acknowledge the valuable assistance given by General A. Trudeau and his staff at the Gulf Research and Development Corporation, U. S. Air Force Historical Office, and the U. S. Air Force Library, members of the staff of ASTIA, and of the Library of Congress, and of other individuals who made us free of their personal recollections of the combat operations.

DISTRIBUTION

U. S. Army Human Engineering Laboratory - 50 copies.
Defense Documentation Center - 20 copies.

APPENDIX I - The Use of the Zero Input Tracking Analyzer in Studies of Human Operators, with Special Reference to AZON.

By

Norman K. Walker
Elizabeth DeSocio
and
Alastair Anthony

Introduction

The test records show that there is a considerable variation in maneuverability between different types of AZON bombs, the impact altitudes differed, and the dropping altitudes ranged from 9,000 to 22,000 feet. Furthermore, in the case of a later development, RAZON, the Norden bombsight telescope with a magnification of 2.25 was used.

As a result the apparent angular stiffness*, which has been shown to be the parameter controlling the accuracy achieved by direct operator control of a missile, varies considerably over the spectrum of results available for analysis, and it is necessary to determine the effect of such variation so that by comparing results on a uniform basis the various degradation factors can be determined.

Other factors of importance, which also varied, are the degree of training of the operator, the technique used by the operator, and the lag between the transmission of a control signal and the achievement of lateral acceleration of the bomb.

All these effects can be investigated readily using basic tracking results from the ZITA II equipment developed for the U. S. Army Surgeon General under Contracts Nos. DA 49-193-MD-2208 and DA 49-193-MD-2369.

THE ZITA II

ZITA II, the Zero Input Tracking Analyzer Type II (Figure 13) is a device which presents a simple tracking task to an operator who is merely required to hold a spot of light in the center of a screen, using left or right correction movements of the control stick. The control law can be varied so that the spot movement is a velocity or acceleration response to stick movement, the stiffness of control can be varied over a range of 1,000:1, and first order lead or lag circuits can be inserted between the control stick and the analog computer section.

* Stiffness , Δ max (mils/sec²) = $\frac{\text{Magnification} \times \text{max. lat. acceleration (ft/sec}^2\text{)}}{\text{Distance (thousands of feet)}}$

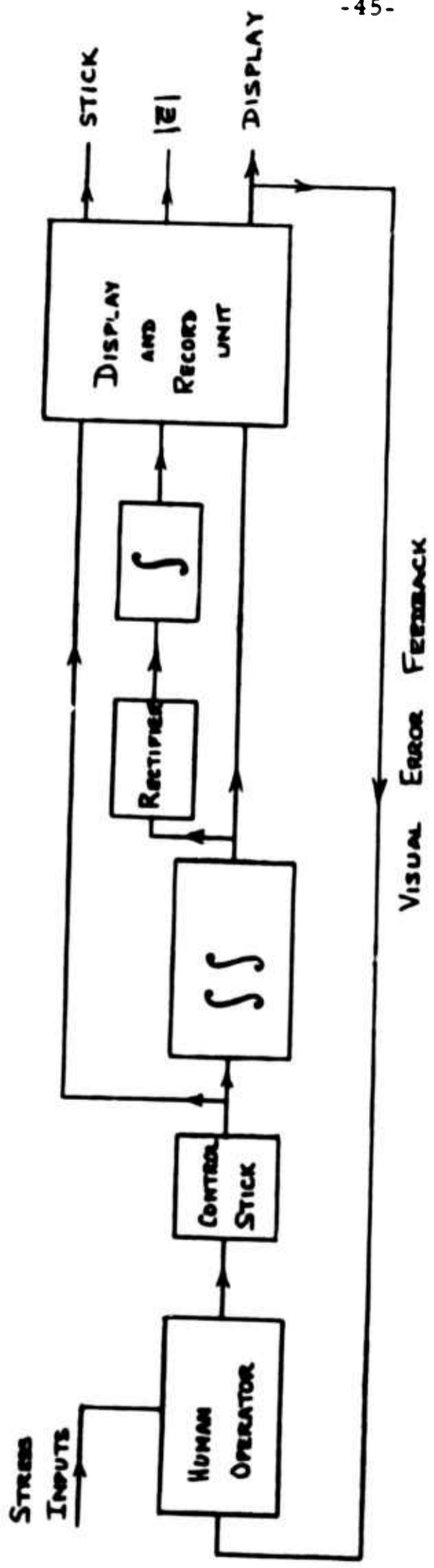


Figure 13. BLOCK DIAGRAM FOR ZERO INPUT TRACKING ANALYZER

Great care has been taken to minimize drift, and to provide a simple and direct readout of error. The readout chosen is the accumulated error modulus, which is taken over a fixed time interval of 57.5 seconds, and can easily be converted to a mean modular error over this interval.

Since the presentation is a spot of light which must be kept on the zero line it is obviously similar to the AZON system in which the operator holds the flare indicating the position of the bomb as near as possible centered on a straight line such as a railroad running into the target.

Rubric Tracking

During the early experimental work¹⁷ for the Surgeon General contract, it was discovered that a most accurate method of controlling the spot was to use two position bang-bang control, in which the stick can only emit two signals, full left or full right -- there being no center position. Proportional control or the addition of a center zero position each merely extended the training time without appreciable gain in accuracy.

This system, as now taught by Norman K. Walker Associates, was named "Rubric" tracking by Dr. Lynn Baker of the Army Research Office, since the operator is required to memorize and use a simple rule to determine when to reverse his control signal.

Figure 14 shows that "Rubric" tracking as practiced by Walker on various occasions is very consistent over a wide range of stiffness and this finding is confirmed by experiments with other operators.

The variation of mean modular error (\bar{e} mils) with stiffness ($\Delta \max$) appears to lie on a curve, tending to two asymptotes. At low stiffness values tends to a fixed minimum, presumably the limit of visual acuity of the particular operator in determining small differences of angle. For high stiffness values \bar{e} is proportional to $\Delta \max$, implying that the frequency of the oscillations of e has reached an upper limit. This is presumably set by the time taken by the operator to decide to move, and then to move the stick.

Tests on a number of subjects have shown that variations in these two limits for service type personnel tend to be related, hence a variation of subject can, in most cases, be represented by a simple factor on \bar{e} . However, the improvement from young servicemen, or even test pilots, over Walker (with glasses) is not great, perhaps 30%.

The effect of a first order lag is to slow down the response of the operator as he must now decide much more accurately when to move the stick. Strangely enough, even at the lowest stiffness tested the effect is still present, so that the

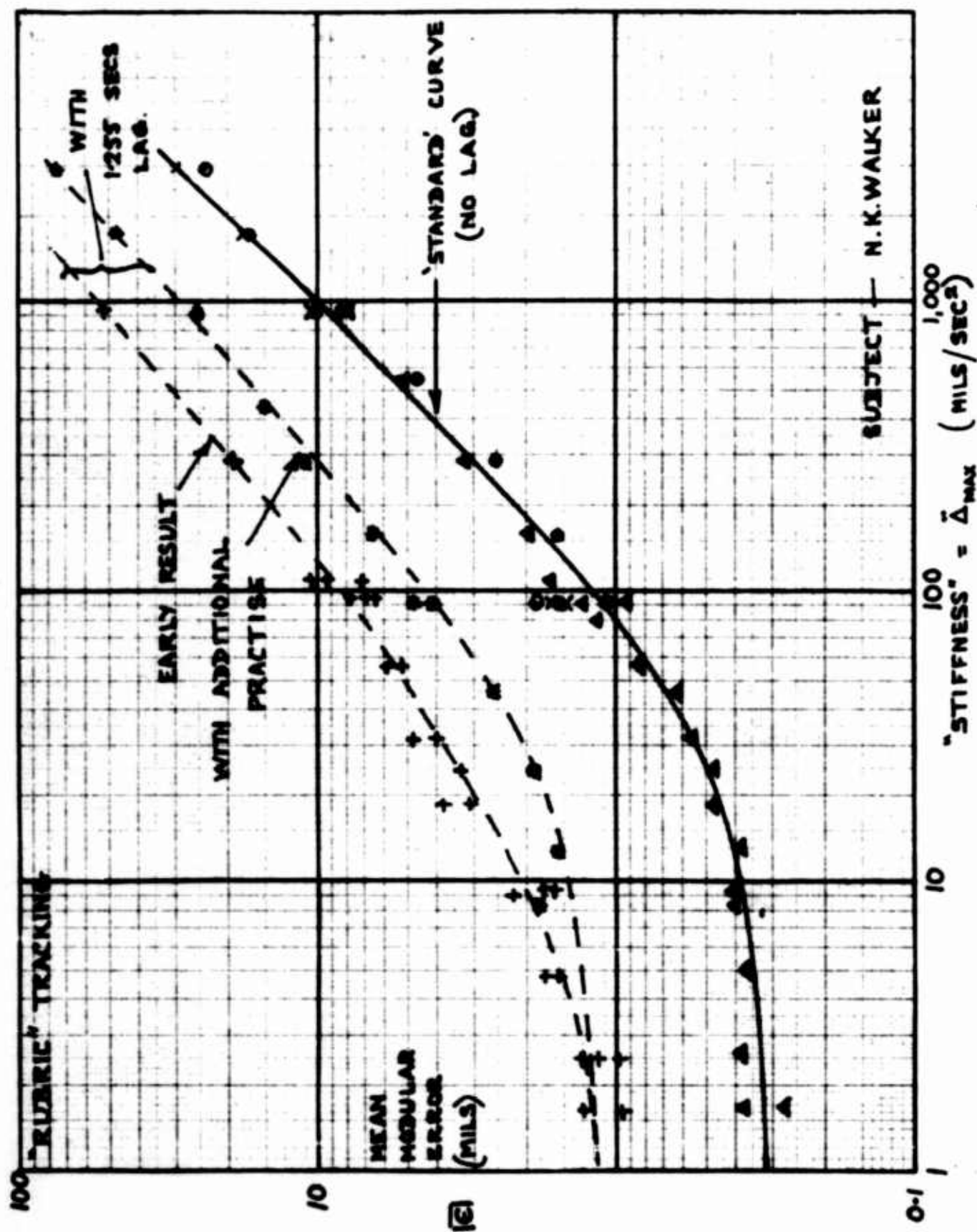


Figure 14. STANDARD VARIATION OF MEAN MODULAR ERROR WITH STIFFNESS

effect of a lag can be represented again by a fixed factor on $|\bar{e}|$, which varies only with the lag and the operator. Presumably the explanation is that at low stiffness the error is set not only by the limit of angle which the operator can detect but also by the limit of angular rate which is much more restrictive. (Figure 14).

3-position Tracking

When the photographic records of AZON drops are examined in detail, it is found that the AZON bombardiers did not use Rubric tracking with 2 positions of control, but gave left or right signals of one or more seconds in duration, interspaced with long periods of zero control.

The authors therefore made a series of tests with ZITA using the 3 position control stick, and deliberately held the control over for a minimum of one second, imitating the bombardiers' technique. The results are also given in Figure 15 and in detail in Figure 16 and show that "3 position control" is inferior to "Rubric" tracking with zero lag but is superior to Rubric with a long lag.

The Effects of "Stress" on Rubric Tracking.

The effect on tracking accuracy (as measured on ZITA II) of various stresses is being investigated by Walker and Fricker.

Some conditions such as alcohol, or hypoxia produce initial improvement in results. while others -- providing acute physical discomfort or mental distraction -- produce a sharp degradation.

Results of one subject in a CBR impermeable suit -- which is extremely uncomfortable to wear after the first hour -- are given in Figure 17 and Figure 18 and show a very large degradation.

A second experiment is summarized in Figure 19. The operator's tracking performance was measured while he was also required to repeat aloud a list of words read to him through earphones at the rate of 3 words/second. With no lag the tracking performance is little impaired, but with 1.0 seconds lag the tracking performance is greatly degraded by the secondary task, as is the performance of the secondary task itself. Further experiments on these lines^{3, 18} show that the impairment to performance is also a fixed factor on $|\bar{e}|$ over the whole gain range, but varies considerably with lag (i. e., with the difficulty of the tracking task).

Examination of the records shows that the normal track is composed of a high frequency and a low frequency component. The effect of lag is to increase the period, and hence the amplitude, of both components, and the effect of stress is to increase the periods of both again, leaving the relative amplitudes largely unaltered.

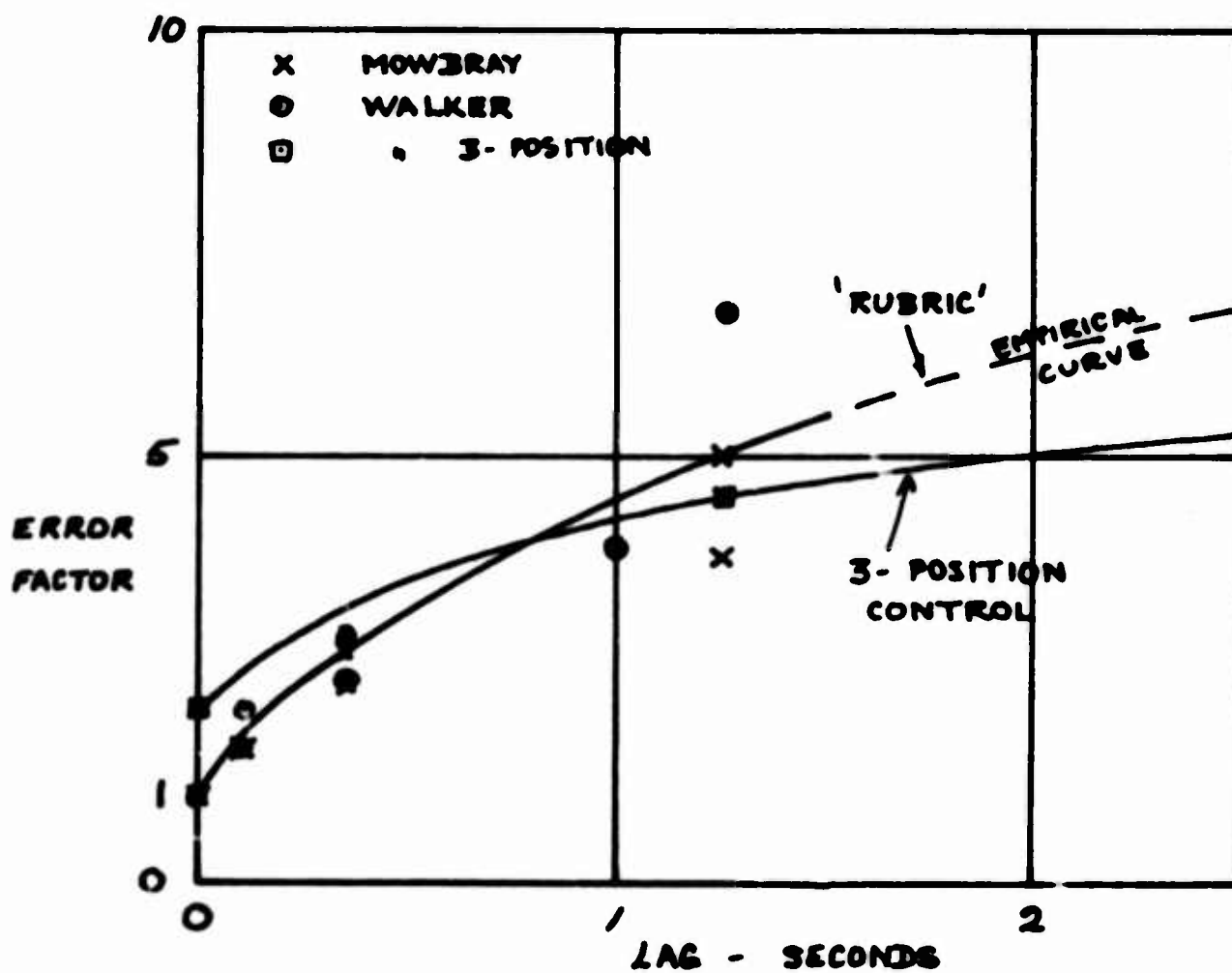


Figure 15. VARIATION OF ERROR FACTORS WITH LAG FOR 'RUBRIC' AND 3-POSITION CONTROL TRACKING

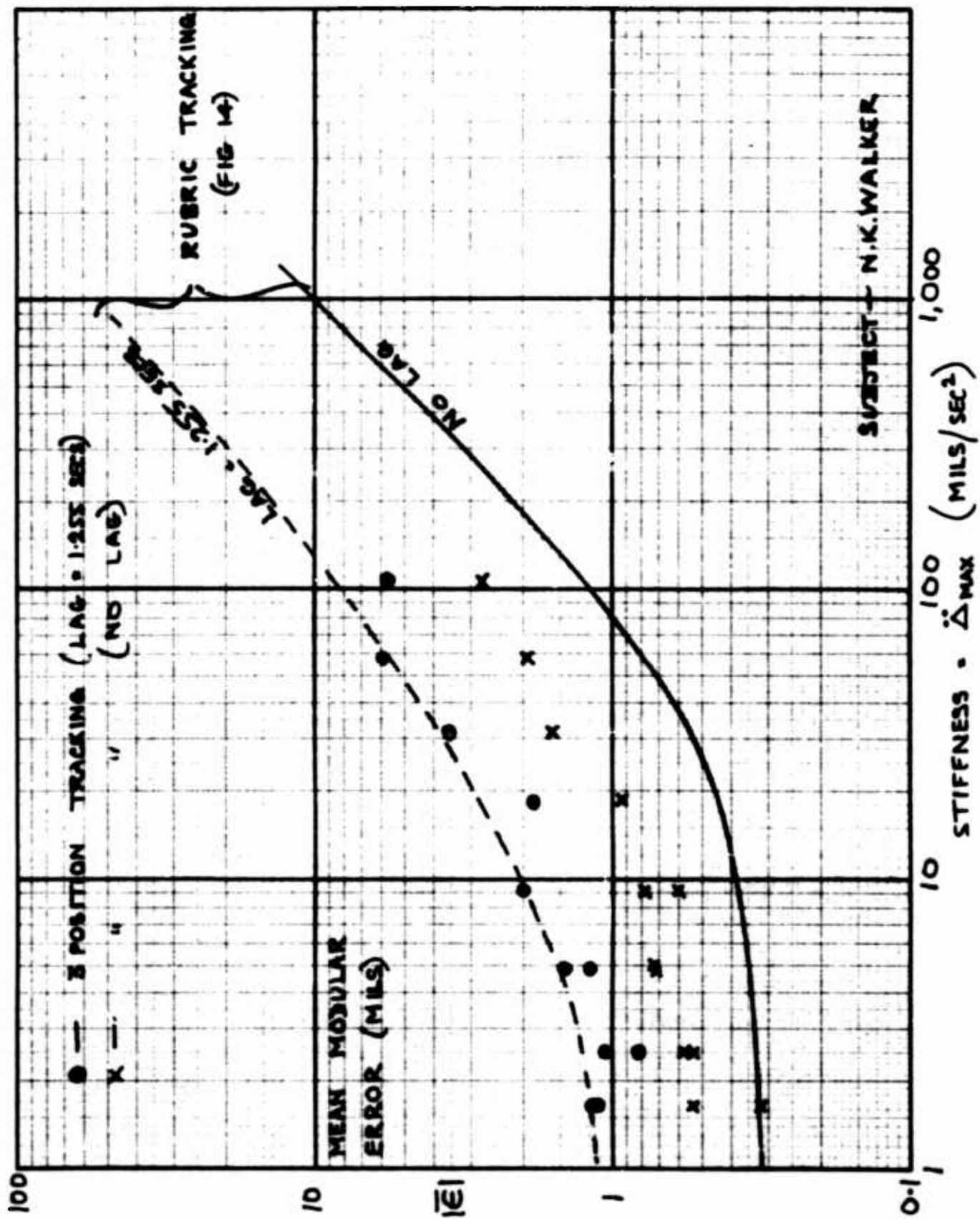
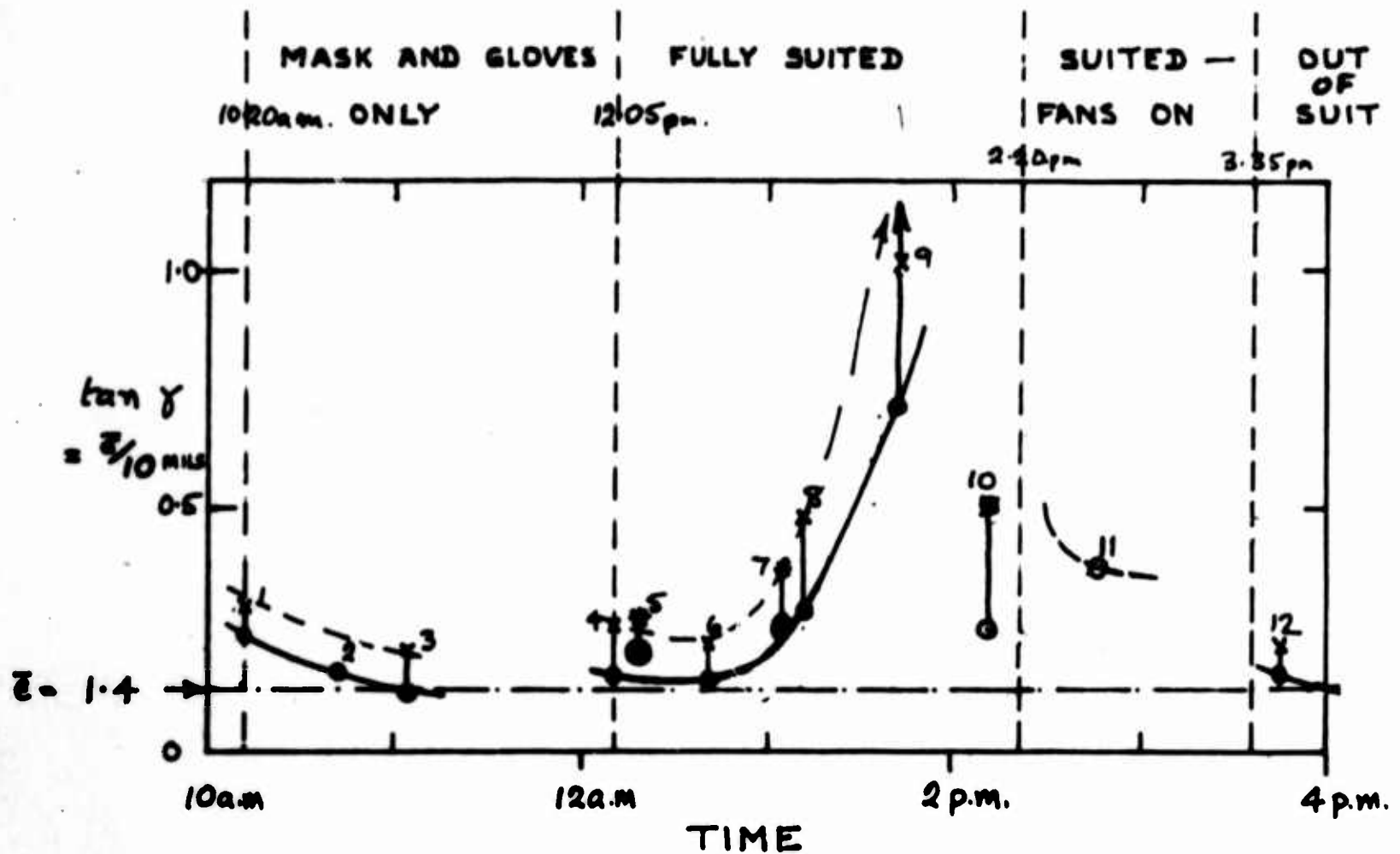


Figure 16. COMPARISON OF ACCURACY OF 'RUBRIC' AND '3-POSITION CONTROL' TRACKING



NOTES —

n.b. STANDARD
ERROR RATIO

$$\frac{\Sigma}{8} = 0.15 \tan \delta$$

$\int \delta$ = SLOPE OF
ERROR TIME INTEGRAL

- — FIRST 100 SECONDS (SEATED)
- ⊙ — " " (STANDING)
- x — LAST 100 SECONDS (SEATED)
- * — " " (STANDING)

RUN 5 — EYES OBSCURED BY SWEAT

" 9 — CONTROL LOST TWICE IN X

" 10 — SUBJECT TOLD BEFOREHAND THAT
THIS WAS LAST HOT RUN

" 11 — POWER FAILED DURING RUN

" 12 — SUBJECT ALMOST RECOVERED

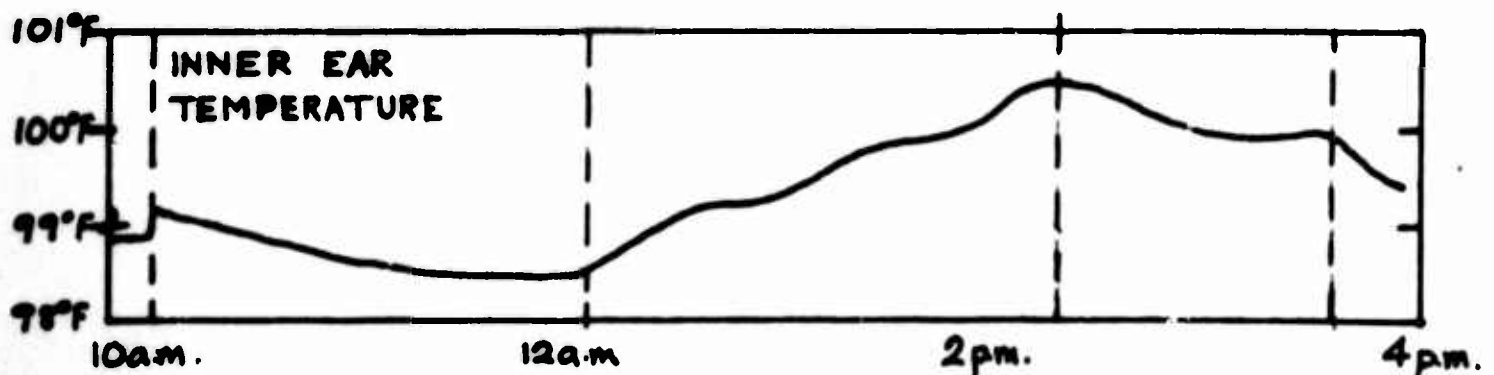


Figure 17. OPERATOR DEGRADATION UNDER THERMAL STRESS
(NAVAL MEDICAL RESEARCH INSTITUTE)

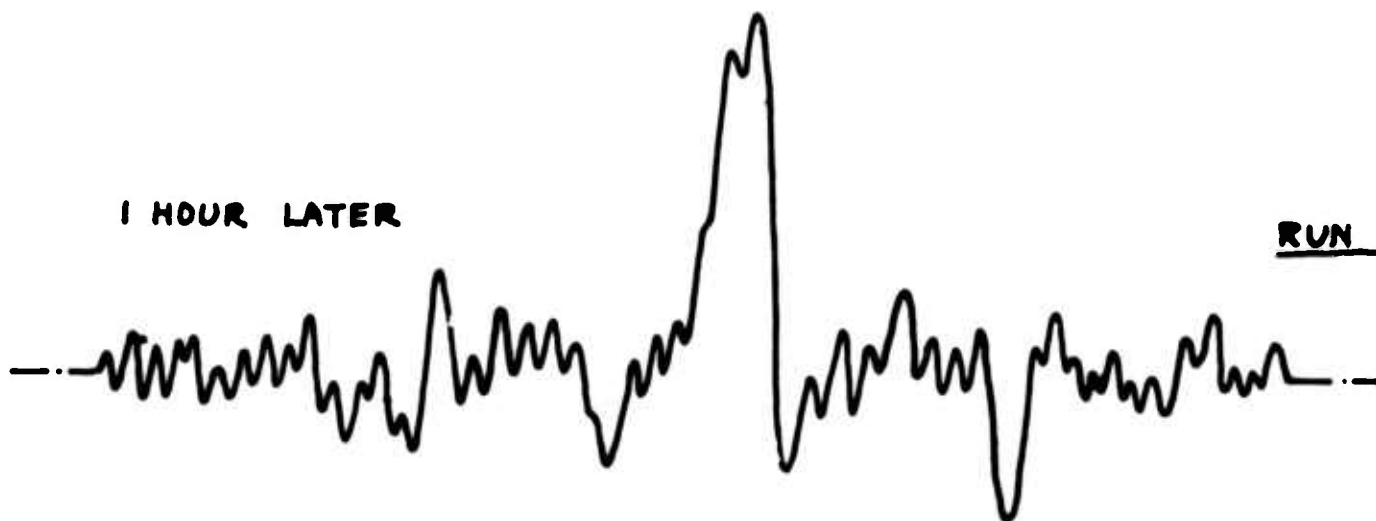
ACCLIMATISED TO SUIT ($\frac{1}{2}$ HR)

RUN 6.



1 HOUR LATER

RUN 9



SUIT REMOVED

RUN 12



SUBJECT - ENSIGN DASLER, N.M.R.I. (SUBJECT . E.)

(FIRST MINUTE ONLY SHOWN OUT OF 4 MIN TEST RUN)

SEE ALSO FIG. 18.

Figure 18. EXTRACTS FROM ZITA RECORDS SHOWING EFFECTS OF THERMAL STRESS AND RECOVERY THEREFROM

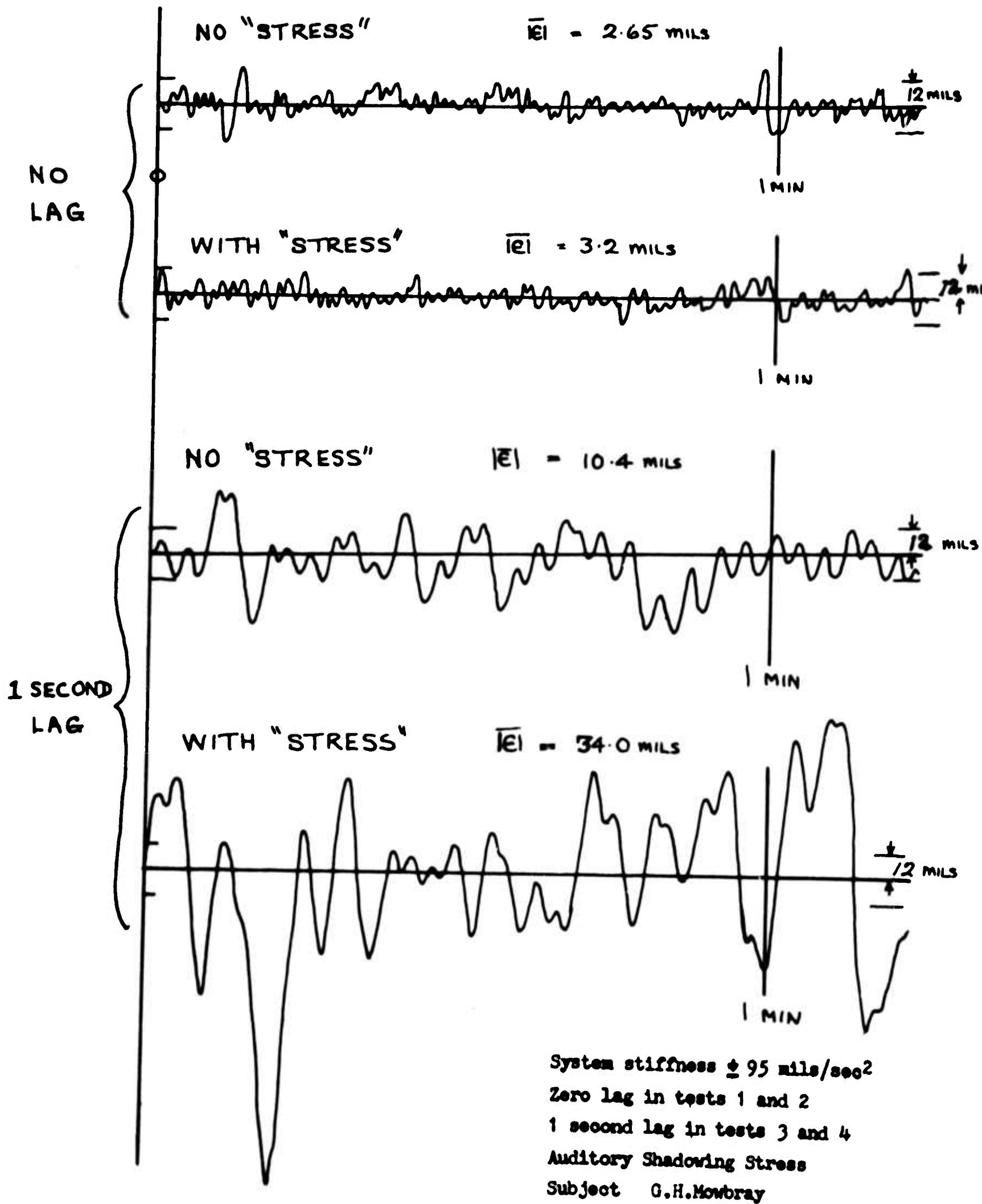


Figure 19. EFFECT OF 'STRESS' ON 'RUBRIC' TRACKING

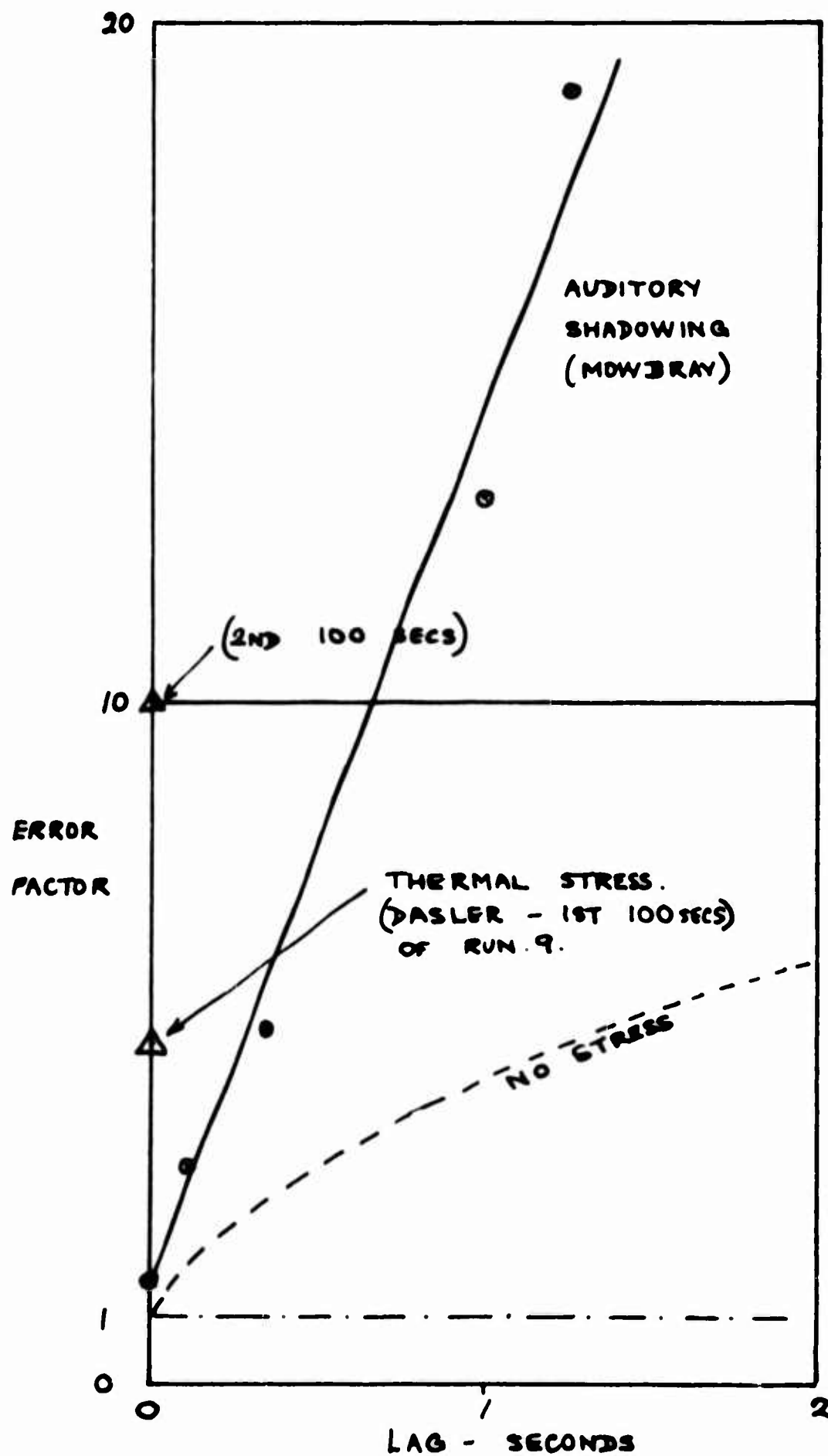


Figure 20. THE EFFECT OF TWO STRESSES ON ERROR FACTOR

Hence if it can be established that the ZITA II record is a close approximation to a typical AZON record, then a detailed examination of combat films might disclose a considerable increase in the amplitude of the path oscillation over proving ground results, and this could well be considered the result of actual combat stress as distinct from general operational degradation.

Comparison of ZITA II records with AZON records

It has been suggested in Part I that the AZON bomb could be simulated by a single axis control system with a stiffness of 1.9 mils/sec² and a time lag of 0.9 seconds. Actually the time lag was due to an electric motor control which was rate limited, but as the actual AZON operators used 3 position control for tracking with dwell times in excess of 1 second the response can be simulated accurately by the first order time lag as built with ZITA II.

ZITA II was taken to Gulf R & D Labs, Pittsburgh, and demonstrated to Mr. R. D. Wyckoff, Dr. T. J. O'Donnell and Mr. E. M. Palmer. * The eye distance was set at 90" which reduced the apparent size of the "missile" light spot until it is small in comparison with the expected 1 - 2 mils error, and the gain was set to give the correct stiffness. To approximate to the rate limited control lag, a first order time lag of 1.25 seconds was included.

The result for Mr. Palmer is shown in Figure 21 and this indicates the following features:

- a. The mean error is obviously greater than the 12' width of the road, but not much greater.
- b. The peak errors are about 35 feet.
- c. There is a short period oscillation with a period of about 6 seconds, imposed on a much slower oscillation.
- d. Frequently the "bomb" lies entirely within the confines of the target for several seconds.
- e. There is a tendency for a very long period oscillation to be present so that the bomb may dwell perhaps 15 feet either side of the target for several short period oscillations, i. e., ± 1 mil for 10 seconds.

Now the results for the first AZON bomb dropped (No. 13) are also given in Figure 21 and show the following characteristics:

*Members of the original team which developed AZON and who actually guided most of the experimental missiles.

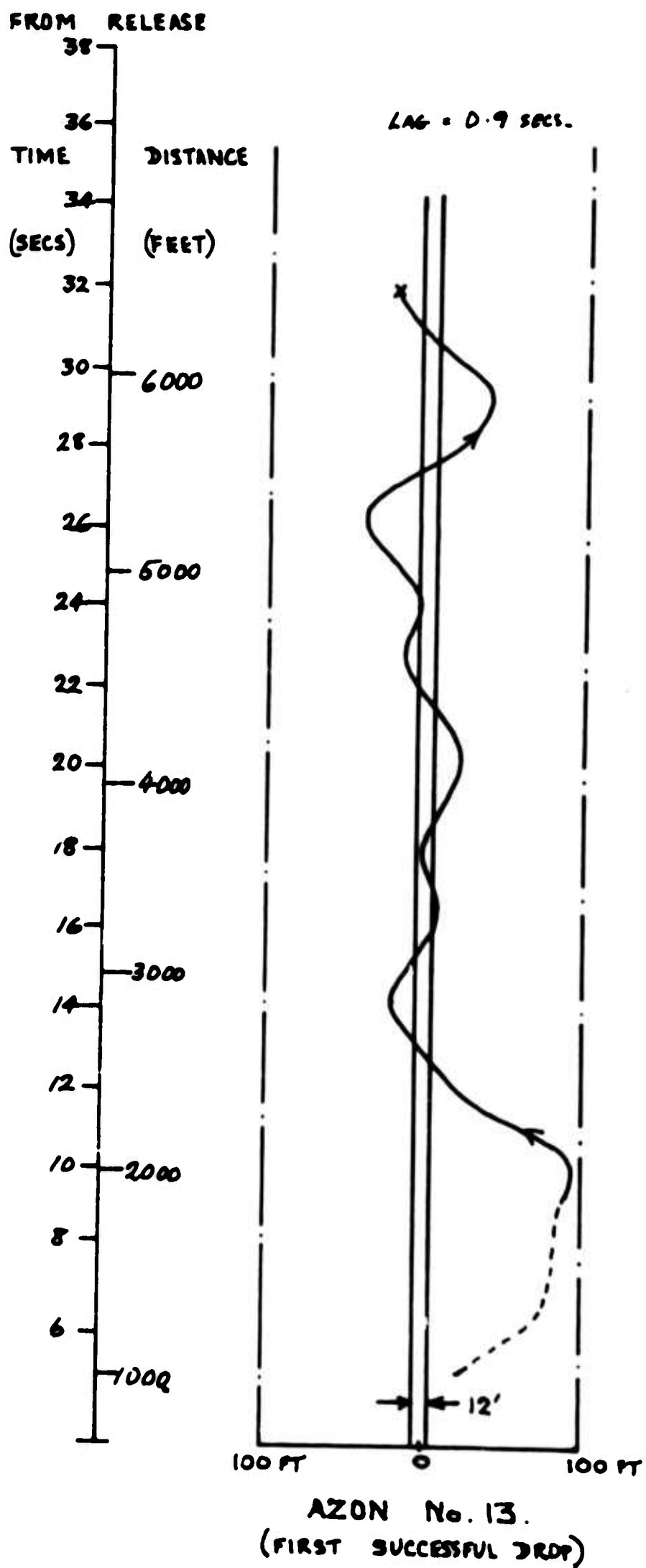
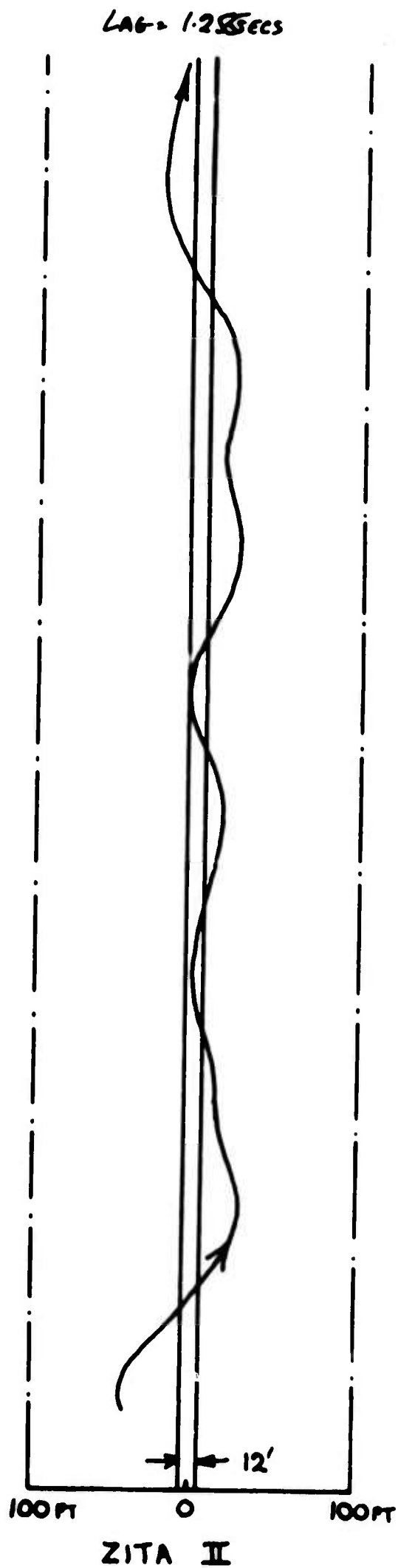


Figure 21. AZON OPERATOR'S RESULTS USING ZTTA COMPARED

- a. A mean error of 0.99 mils (15 feet) 2-1/2 times the half width of the roadway.
- b. A peak error, well after launch, of 42 feet.
- c. 8 half cycles in 19 seconds, or an average period of about 5 seconds, imposed on a much slower oscillation.
- d. Occasions when the bomb for a second or two would lie entirely within the road target.
- e. A tendency to lie to one side or other of the target for several weave oscillations.

This agreement is therefore very marked and would probably be improved with a reduced time lag, which would speed up the short period oscillation, and a correct simulation of the rate limited servo. The tendency to lie to one side of the target for 10 seconds or more is most interesting, as it was shown to be present with AZON tracks in the main body of the report, being termed "aim" error, since it is substantially constant during the terminal 10 seconds of flight.

It was therefore concluded -- and the Gulf representatives all agreed -- that with suitable scaling the ZITA II results are strictly comparable to the actual behavior of a real AZON bomb, and that useful deductions about the behavior of AZON may be made from the ZITA results.

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<p>REPORT NO. 8</p> <p>Norman K. Walker Associates, Inc., Bethesda, Md.</p> <p>"The Accuracy of the Azon Guided Bomb as Affected by Battle Conditions in World War II."</p> <p>The accuracy achieved with the AZON human operator guided bomb in World War II is investigated and compared with German experience on similar missiles. Considerable</p>	<p>UNCLASSIFIED</p> <p>(1) Human Factors</p> <p>(2) Guided Missile Control and Guidance</p>
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